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1993 Fleet Doctrine Evaluation Workshop: Phase I — Class A Fire/Vertical Attack

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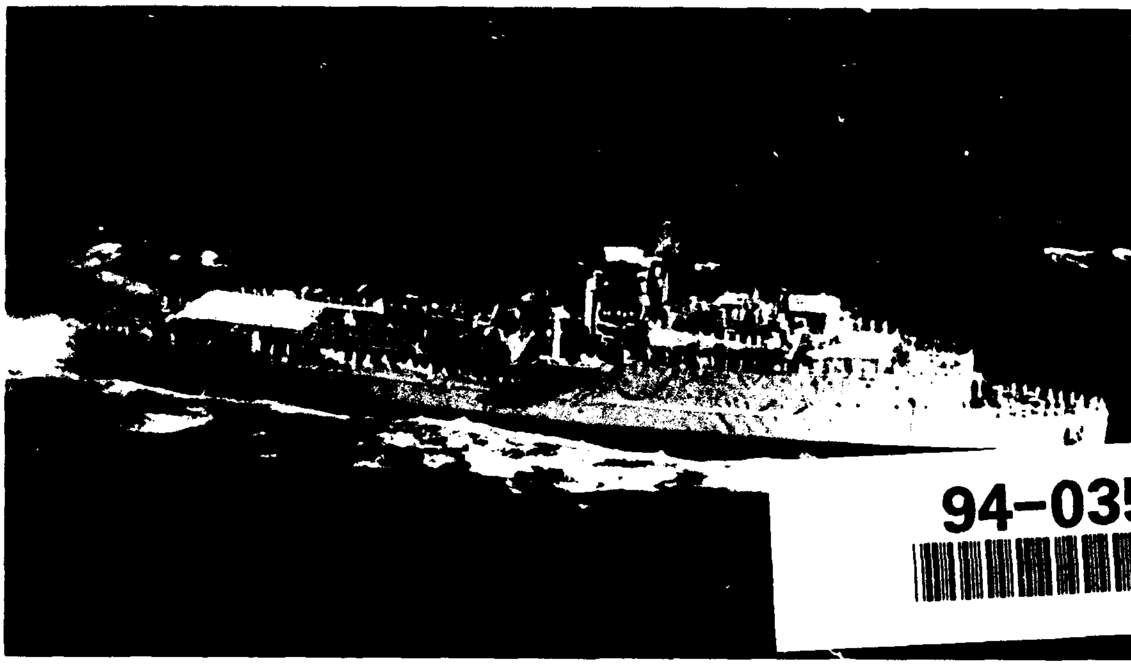

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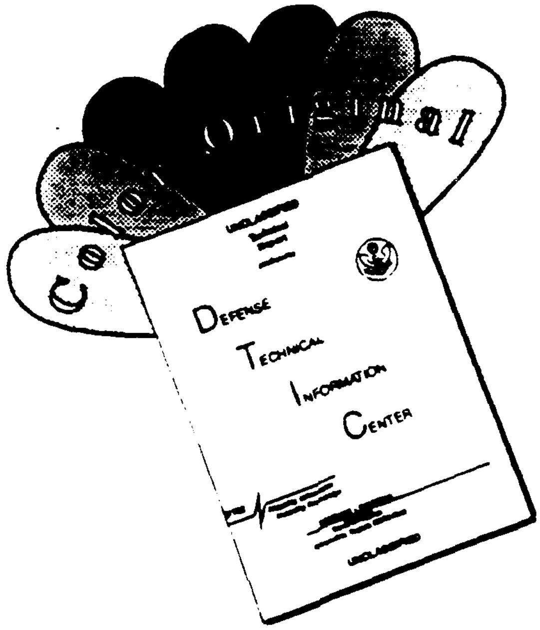

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A series of firefighting tests were conducted to develop and refine firefighting doctrine for vertical attack of a Class A fire in a below-decks, limited access space. Key findings in this test series included using an access team to gain entry to the space and monitoring pressure build-up when indirect firefighting is used. Cool vests provided a significant improvement in the reduction of heat stress. Too much communication, particularly between the Team Leader and On-Scene Leader, can hinder the effectiveness of firefighting. Cooling of spaces used to gain access to a fire can create steam that makes the space temporarily untenable. Active desmoking during the firefighting attack can improve the overall damage control effort.

Based on these and previous Fleet Doctrine Evaluation Tests, it is proposed that NSTM 555 and NWP 62-1 be revised to include doctrine and tactics for vertical attack and active desmoking of a Class A fire.

14. SUBJECT TERMS

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List of Abbreviations

CIC	Combat Information Center
FPL	Fire plug
FR	Frame
ISMS	Integrated Survivability Management System
JD	Joiner door
LPES	Limited Protection Exhaust System
LPSS	Limited Protection Supply System
NDI	Non-Developmental Item
NFTI	Navy Firefighters Thermal Imager
QAS	Quick acting scuttle
QAWTD	Quick acting watertight door
QAWTH	Quick acting watertight hatch
TPES	Total Protection Exhaust System
TPSS	Total Protection Supply System
WIFCOM	Wire-free communications
WMF	Water motor fan
WR	Washroom
WTD	Watertight door
WTH	Watertight hatch
WTS	Watertight scuttle

1993 FLEET DOCTRINE EVALUATION WORKSHOP: PHASE I — CLASS A FIRE/VERTICAL ATTACK

1.0 INTRODUCTION

The tests described in this report represent a continuation of the Fleet Doctrine Evaluation (FDE) tests onboard the ex-USS SHADWELL, the Navy's full-scale damage control R&D platform [1]. The initial series in 1991 focussed on indirect attack of mass conflagrations [2]. The 1992 test series included experiments with a simulated chemical round hit and with active desmoking of a below-deck Alpha fire [3-4]. Both the 1991 and 1992 workshops emphasized smoke and heat management techniques.

There continues to be issues with the Fleet concerning procedures for a downward or vertical firefighting attack through a hot thermal layer, e.g., down an inclined or vertical ladder or escape trunk. General procedures for working down an escape trunk ladder to a machinery space were developed on the SHADWELL [5]. However, these tests were limited because there was no fire involved. The 1993 FDE tests were intended to build on the previous experiments. The challenge in Phase I was a vertical attack via an unenclosed ladder on a limited-access space below decks, e.g., berthing space, storeroom, or pump room. For this test series, it was assumed that a horizontal attack was not possible. Alternative methods of firefighting attack were evaluated, along with different desmoking strategies. As usual, ancillary tests were piggybacked onto the active firefighting tests. These supplementary tests included work with psychological stress, ice vests, the Integrated Survivability Management System (ISMS), sensors, damage control asset management, and Non-Developmental Item (NDI) equipment.

The objective of this report is to document the test setup, describe the results of the firefighting tests, and provide representative data of the threat. It is expected that principal investigators/project managers for piggyback tests will prepare individual reports/videos/presentations.

2.0 BACKGROUND

2.1 Firefighting

Physical reentry into a space with a major Class A or B fire is a significant challenge for a fire party. The Internal Ship Conflagration Control (ISCC) tests conducted on the port wing wall of the ex-USS SHADWELL focussed on indirect methods [2]. The fire party had the advantages of working from the weather and having

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a horizontal attack point. For below-decks situations, the fire party may be forced to attack a fire vertically via an inclined or vertical ladder. This ladder may or may not be enclosed in a trunk or vestibule. Attack down a vertical ladder which is enclosed in a trunk or vestibule is generally considered easier than down an unprotected ladder. The trunk or vestibule provides protection from the hot layer of the compartment and provides a staging point to enter the space [5].

The classic situation where an attack must be made vertically is for machinery spaces. However, other spaces present a similar challenge. These spaces include second, third, and fourth deck berthing areas and storerooms, where the primary challenge results from Class A materials. For spaces below the damage control deck, vertical entry to a compartment is the norm, not the exception. Pump rooms and ancillary machinery spaces have Class B fire challenges. The Navy recognizes these challenges, and fixed fire suppression systems are generally provided for these spaces. Fixed protection is not universal, particularly for berthing spaces and storerooms where sprinklers have only recently been specified in the GENSPECS as is found in DDG 51 class ships.

Naval Weapons Publication NWP 62-1 and Naval Ships Technical Manual NSTM 555 are generally silent on tactics and procedures for attacking a fire vertically down an unenclosed ladder. The next version of NSTM 555, now available as an advance document, incorporates lessons learned and sketches of procedures for progressing down an escape trunk. Although developed with machinery spaces in mind, these tactics may be applied to any situation. The change is incorporated in Chapter 5.9.3 of NSTM 555, "Typical Difficulties in Fire Fighting," and may be used as guidance for a Class A or B situation. This is based on non-fire evolutions conducted on the SHADWELL [5]. Otherwise, NSTM 555 advises that reentry into a machinery space should be made through the access, main door, hatch, or escape trunk which is not obstructed by fire (555 — 6.3.10.b.2). The nozzleman is advised to use the reentry Aqueous Film Forming Foam (AFFF) hose wide-angle fog to cool metal surfaces and protect himself (555 — 6.3.10.b.3). In terms of specific Class A vertical reentry procedures, i.e., attacking through the hot thermal layer down an unenclosed vertical ladder, NSTM 555 does not provide specific guidance.

The challenge when working down a vertical inclined ladder is working on the hot deck above the fire and penetrating the thermal layer in the fire compartment. Class A and B fire reentry tests have been performed at the Navy's Treasure Island training facility. Protective gear used in the tests included Nomex engineering coveralls over underwear or dungarees. Proximity suits and normal shipboard clothing were also evaluated. Flash hoods, gloves, helmet liners, and OBAs were worn in all tests. Class B fire tests were conducted in the machinery space mock-up [6]. Access was via a 3.7 m (12 ft) long tunnel to an inclined ladder leading to a 70 m^2 (750 ft^2) bilge fire one level below. Temperatures in the compartment overhead and tunnel overhead were on the order of 399-538°C (750-1000°F). Different nozzle and personnel protection options were evaluated. A continuous application of AFFF was used to combat the fire, which was extinguished in 1.5-2.5 minutes. The results of these tests are reflected in the current machinery space doctrine which describes the advantages of a single AFFF handline attack (with back-up ready and available) and the disadvantages of simultaneously using multiple handlines. The primary limitation of these tests was the staging of the attack at weather, which generally is not realistic aboard ships.

Class A storage space fires were conducted at Treasure Island in a 9.1 x 4.6 x 3.0 m (30 x 15 x 10 ft) space [7]. The fuel was a large wood crib. The fire was attacked horizontally from a bulkhead doorway. There was a modest thermal threat, on the order of 121-149°C (250-300°F). Again, it was found that dual hoses used simultaneously were counterproductive. No vertical attack was attempted.

Ventilation and desmoking procedures for such situations are now based on a traditional, horizontal attack and on the special "mass conflagration" situation. NWP 62-1 requires that

a. When the space is abandoned, the affected space should be mechanically and electrically isolated to the maximum extent possible (9.3.1); and

b. The decision to secure ventilation must be made on-scene with the ventilation secured when firefighters with OBAs arrive (9.3.1.).

NSTM 555 also provides ventilation and desmoking details. Additional ventilation and desmoking doctrine for NSTM 555 is being drafted as a result of the 1992 SHADWELL tests, concepts of which were incorporated into the current testing. A key piece of data still missing is the ability to judge when to safely ventilate a Class B fire. The potential for backdraft during or after a Class A fire is considered minimal, hence venting of adjacent spaces is considered a viable option. This will be reflected in an NSTM 555 revision. Initial attempts to quantify the risk associated with venting Class B fires will be performed in Phase II of the test series (July 6-15, 1993).

2.2 Damage Control

The current FDE tests provided an opportunity to investigate integrated damage control scenarios. Four aspects of damage control are of interest: ISMS, repair and recovery from flooding, rescue of a incapacitated individual and personal protection gear.

An ISMS workstation annex was installed in Repair 2 and the newly formed DC Central on the SHADWELL. The tests provided an opportunity to exercise various components of ISMS, including software packages and communications.

Repair and recovery from a flooding incident are often considered in isolation from a fire incident. Yet, flooding may well occur simultaneously with a fire incident, e.g., due to a collision or detonation of a mine. The FDE tests provided an opportunity to integrate a simultaneous flooding and fire casualty. Because of limited manpower, this option was not exercised in Phase I. The physical setup was completed so that during the Phase III Fleet Workshop the flooding and fire casualties can be integrated.

Rescue of a downed sailor during a casualty has not been considered on the SHADWELL in previous experiments. Again, it is likely that rescue may well be needed during a damage control evolution. Phase I provided an opportunity to evaluate equipment options for confined space rescue.

Personnel protective gear continues to attract attention. The cool vest equipment has been subjected to considerable testing, both in the laboratory and aboard the SHADWELL. The FDE tests provided an opportunity to investigate improvements to the cool vest and observe firefighting equipment under live fire conditions.

3.0 OBJECTIVE

The objective of the Phase I test series was to develop a fire threat and scope firefighting doctrine and tactics for vertical attack of a Class A fire in a below-decks, limited access space. The tests provided an opportunity to investigate heat stress and modifications to the cool vest gel packs, integrate ISMS hardware and software, evaluate damage control asset management system (DCAMS), and evaluate fire sensors. Repair locker and repair party procedures and equipment were also evaluated.

4.0 APPROACH

The FDE tests were conducted in the forward area of the ex-USS SHADWELL between FR 9 and 22 on the first, second, and third decks (Figs. 1-3). The fire area was on the third deck between FR 15 and 22 (Fig. 3). This space was designated as the Crew Living Space 2 or, more informally, Berthing 2 (3-16-0-L). Access was via Crew Living Space 1 (Berthing 1) on the second deck, FR 15-22, down a newly installed inclined ladder (Figs. 2 and 4). Repair 2 (2-9-1-Q) was utilized for these tests and was modified with a small annex where ISMS resided and control electronics for advanced fire sensors (Fig. 5).

In the Phase I test series, a Class A fire was fought using a vertical attack down an unprotected inclined ladder. Test variables included the magnitude of the fire threat, tactics for controlling/extinguishing the fire, and effects of ventilation on smoke/heat management. A series of background burns were performed. Based on the background burns and initial firefighting tests, two threat levels were established. A hands-on evaluation was performed during the time period of 26 April - 7 May 1993. A safety team, led by members from the Surface Warfare Officers School (SWOS), used alternative firefighting and venting strategies to combat the fire and control smoke/heat spread during the first work-up week. In the second week, they were assisted by DC personnel from the USS JESSE L. BROWN (FF 1089), stationed at NAVSTA Mobile. During "down" times between fires, confined space rescue procedures were evaluated. The Naval Health Research Center (NHRC), ISMS researchers, and sensor researchers from NRL Stennis and NSWC with advanced sensorsparticipated in Phase I. NAVSEASYSCOM personnel also participated in specific evaluations.

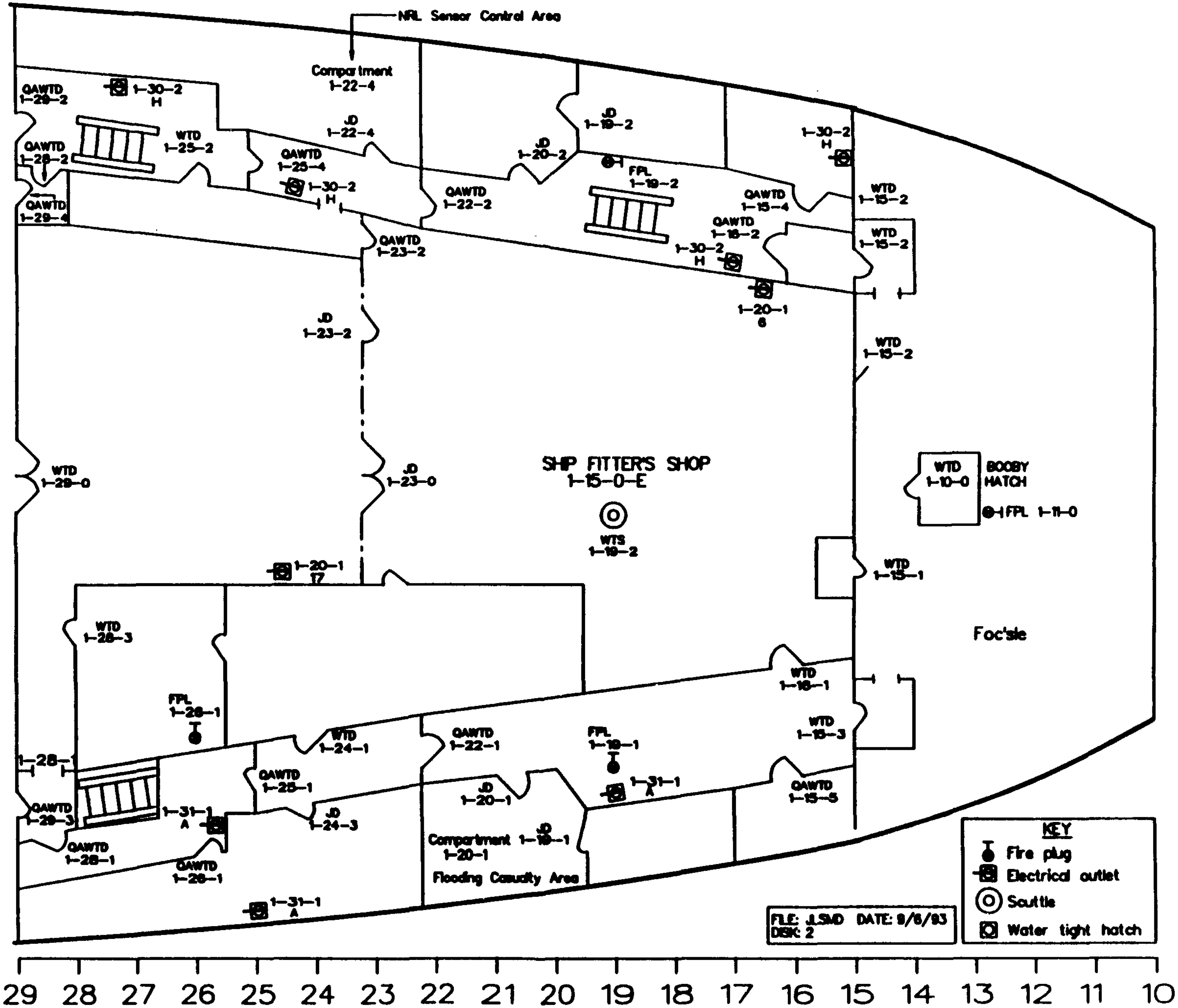


Fig. 1 - Main deck plan view

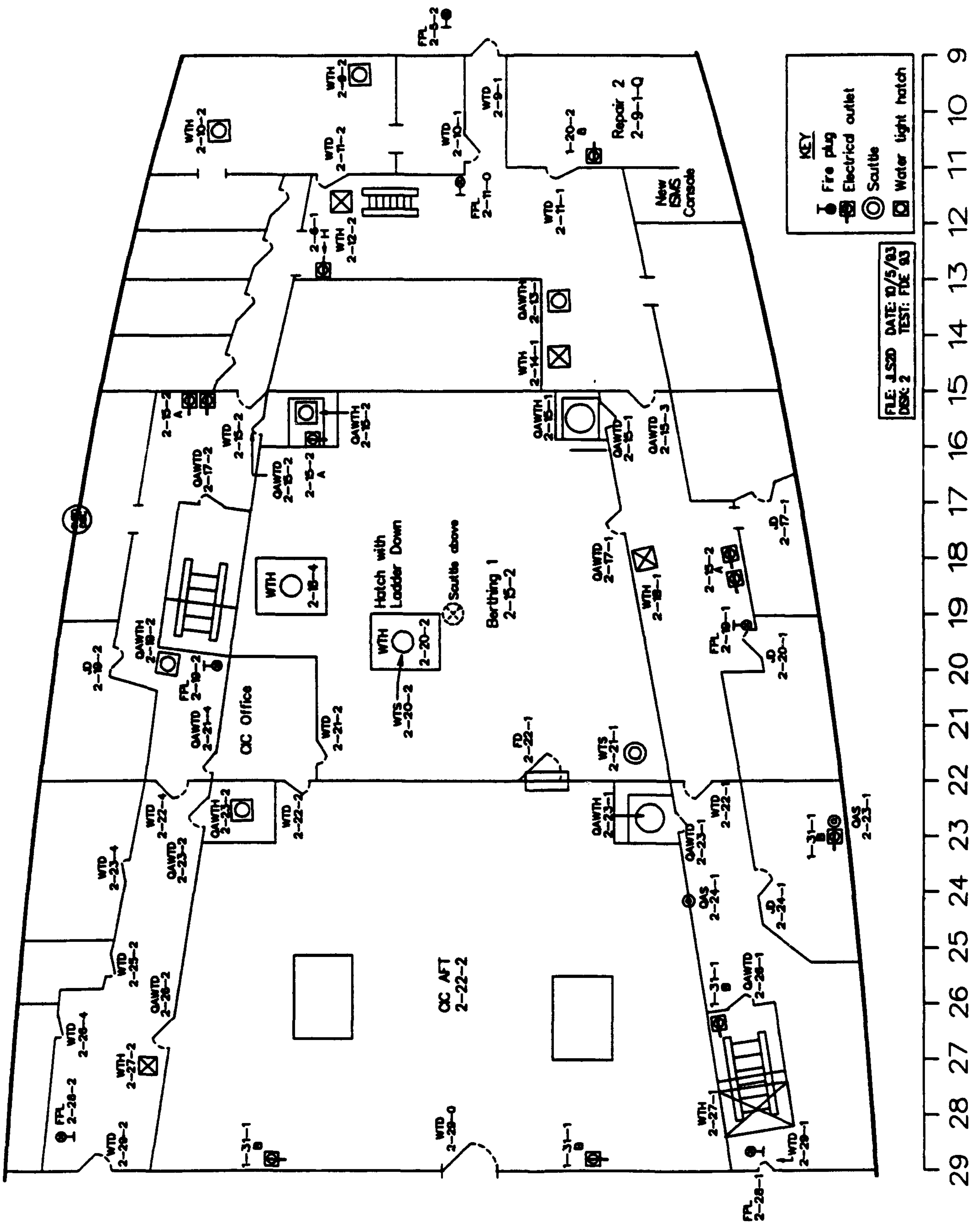


Fig. 2 - Second deck plan view

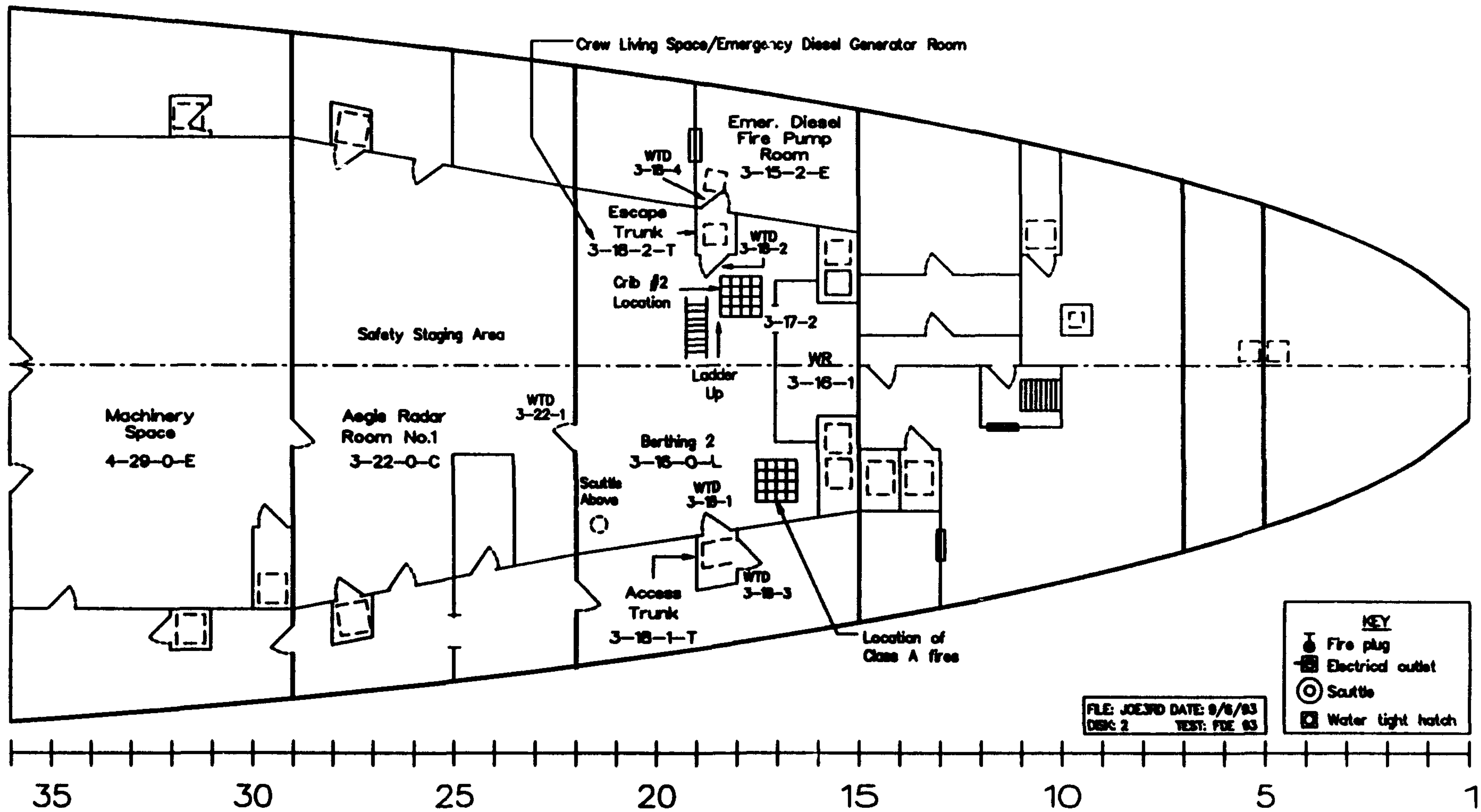


Fig. 3 - Third deck plan view

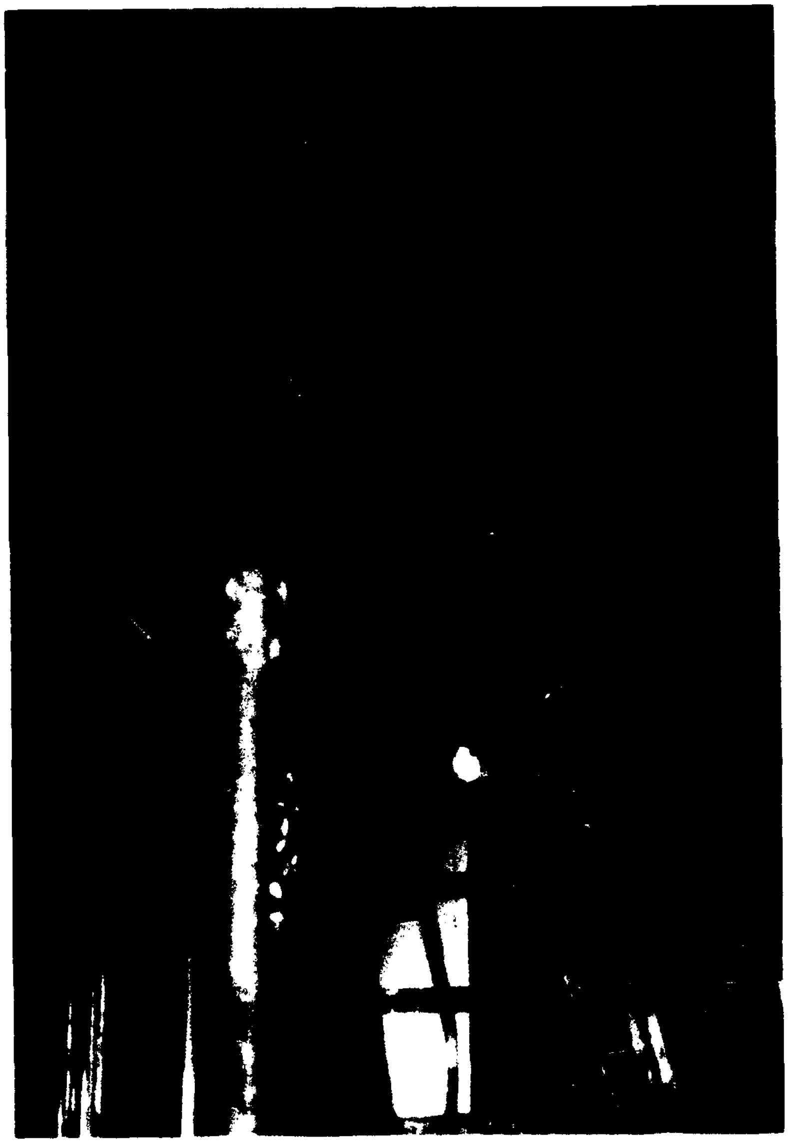


Fig. 4 - Inclined ladder at WTH 2-20-2 leading from Berthing 1 to Berthing 2

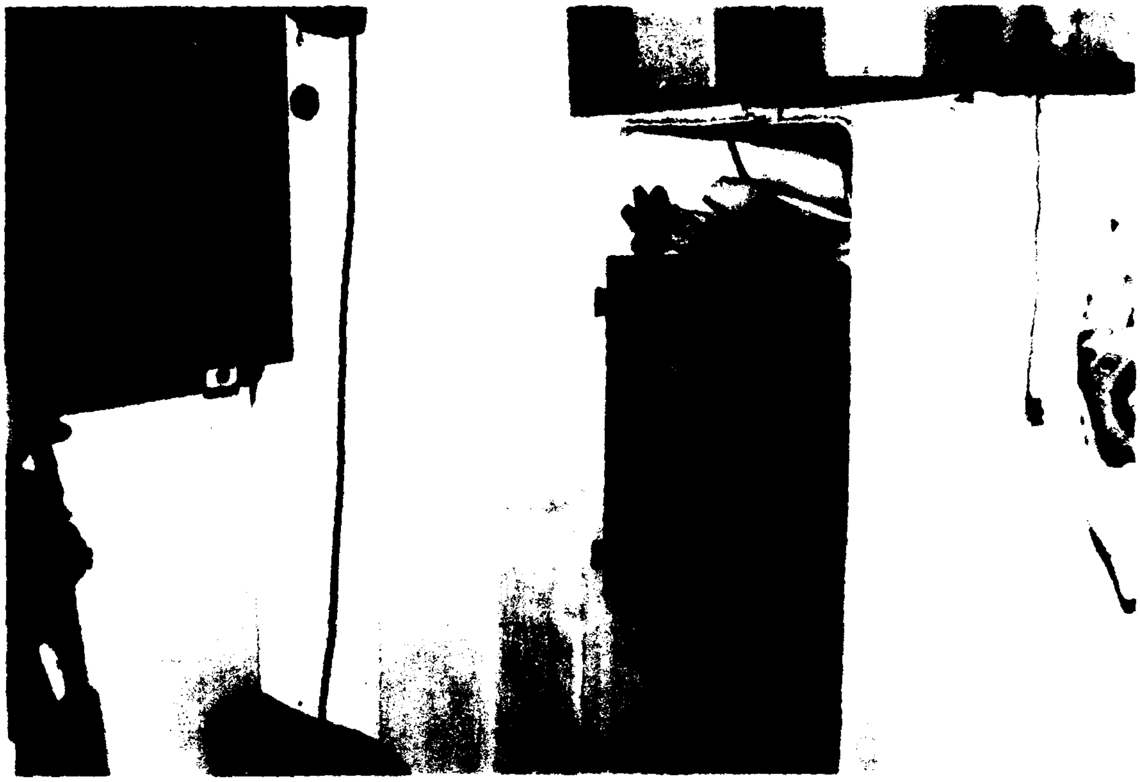


Fig. 5 - ISMS annex in Repair 2

The proposed test plan for the entire 1993 FDE test series is described in Reference [8].

The scope of the Class A tests in Phase I was limited to the fire party attack team. The requirements for a full repair party will be considered in Phase III. The scenario involved a medium-to-high heat threat for a space which would require vertical access for entry, e.g., a below decks berthing space or storeroom. Fire spread was not considered in these tests, e.g., boundaries were not set.

It was assumed that the ship is inport at Condition Four and that Condition YOKE is set. The scenario is a collision where another ship rams the SHADWELL which is berthed. The shock of the collision results in an ignition of Class A materials below decks. The Inport Fire Party, under the direction of the Fire Marshal, responds to the emergency. For the Phase I tests, the Fire Marshal elects to handle the fire without the assistance of General Quarters, fire based fire department, with the concurrence of the Commanding Officer.

5.0 EXPERIMENTAL SETUP AND PROCEDURE

5.1 Setup

In Appendix A, Figures A4 through A6 show the details of the main, second, and third decks. Dimensions of the spaces are noted on these Figures. Accesses used by the Fire Party to enter the space were QAWTD 2-17-1 and WTH 2-20-2. This hatch, with an integral scuttle, WTS 2-20-2, was installed in the deck of Crew Living 1 with an inclined ladder leading from Crew Living 1 on the second deck to the Crew Living 2 on the third deck (Fig. 6). The ladder is located at approximately mid-compartment. WTS 2-21-1 and WTS 1-19-2 were used to ventilate the area to weather via WTD 1-15-1 in the Shipfitter's Shop. The dimensions of the quick-acting watertight doors are 168 x 66 cm (66 x 26 in.) and the watertight hatches are 152 x 76 cm (60 x 30 in.). The diameter of the scuttles are 46 cm (18 in.). Emergency exit routes available to the fire party were WTD 3-22-1 to the well deck via the DDG 51 machinery space; WTD 3-18-1 through the vertical trunk to the second deck and then to the foc'sle via the booby hatch at FR 11; and WTD 3-18-1 to the DC passage on the starboard side. In addition, WTD 2-22-1 allowed emergency access to the machinery space via CIC Aft.

To further simulate crew living spaces, berthing materials such as bunks and lockers were added to Crew Living 2. Figures 7 and 8 show the configuration of the space after the 6th firefighting test.

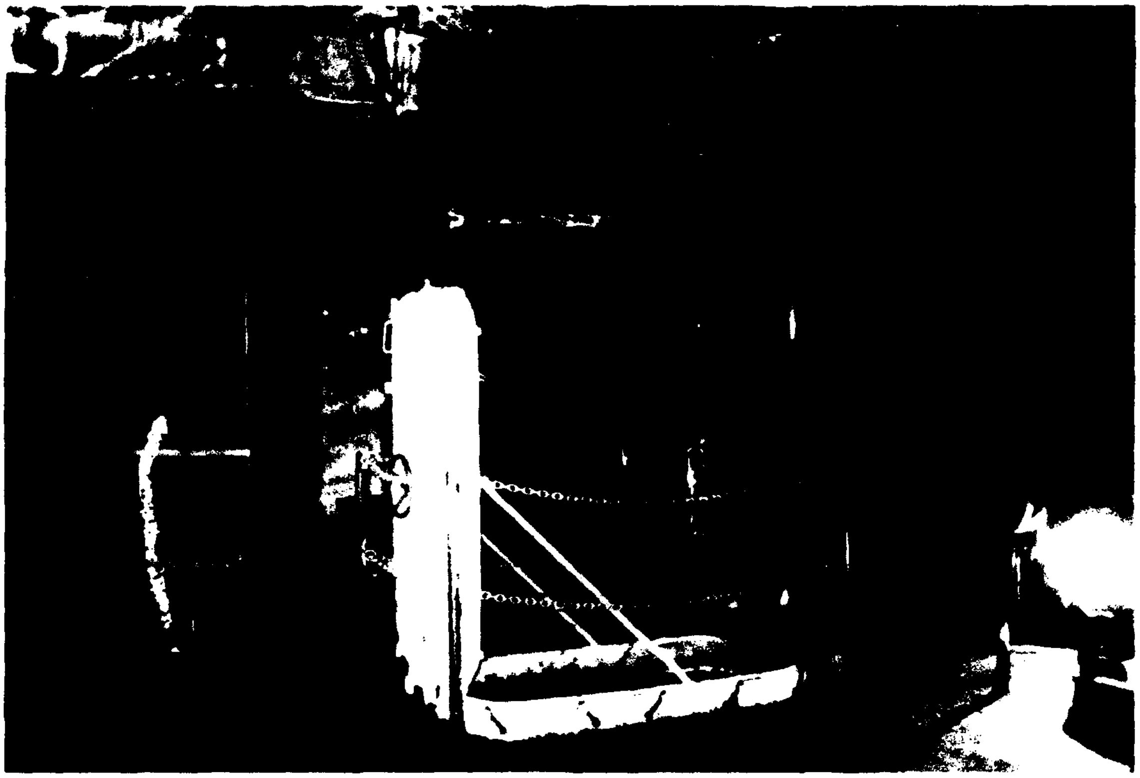


Fig. 6 - WTH 2-20-2 with integral scuttle, WTS 2-20-2

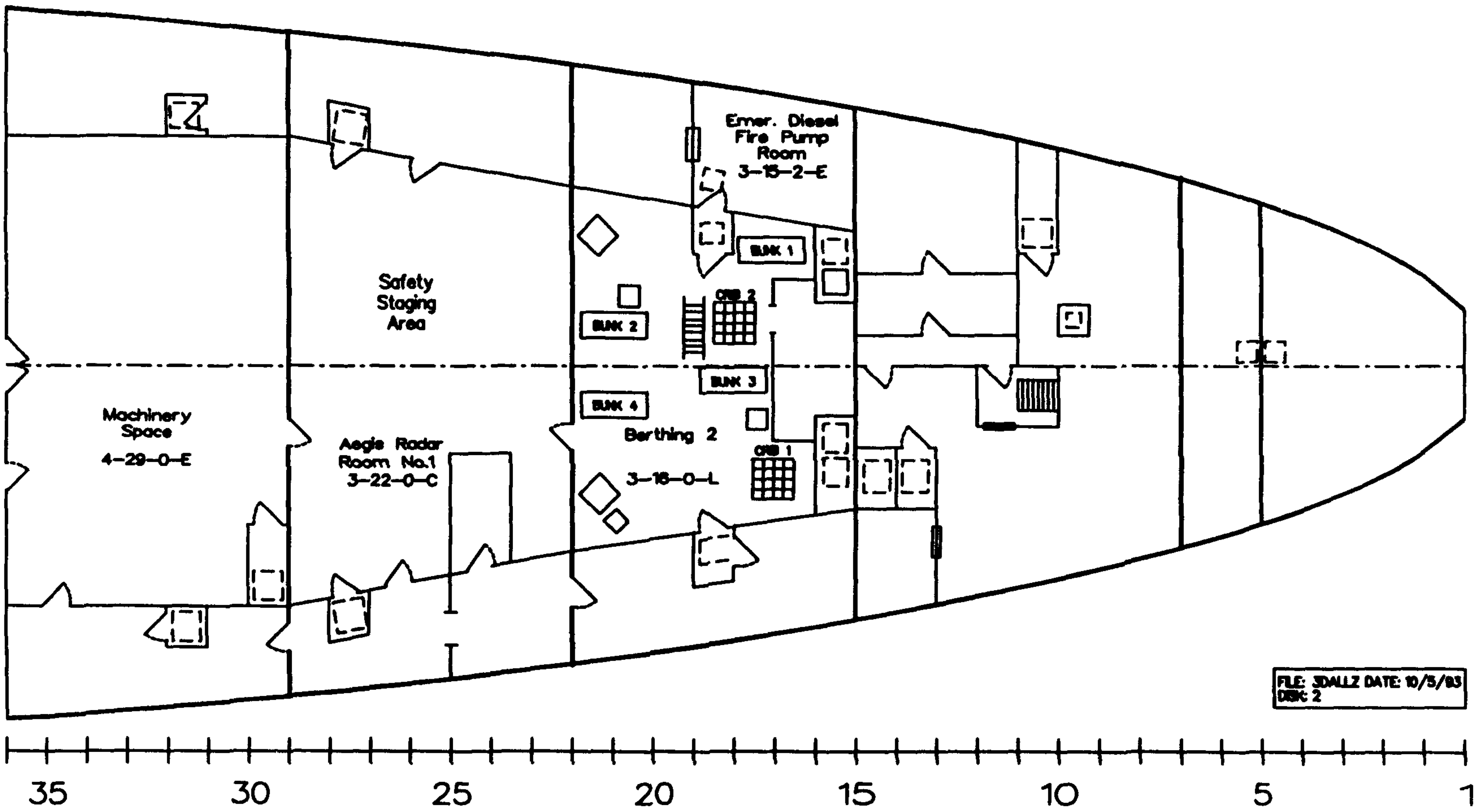
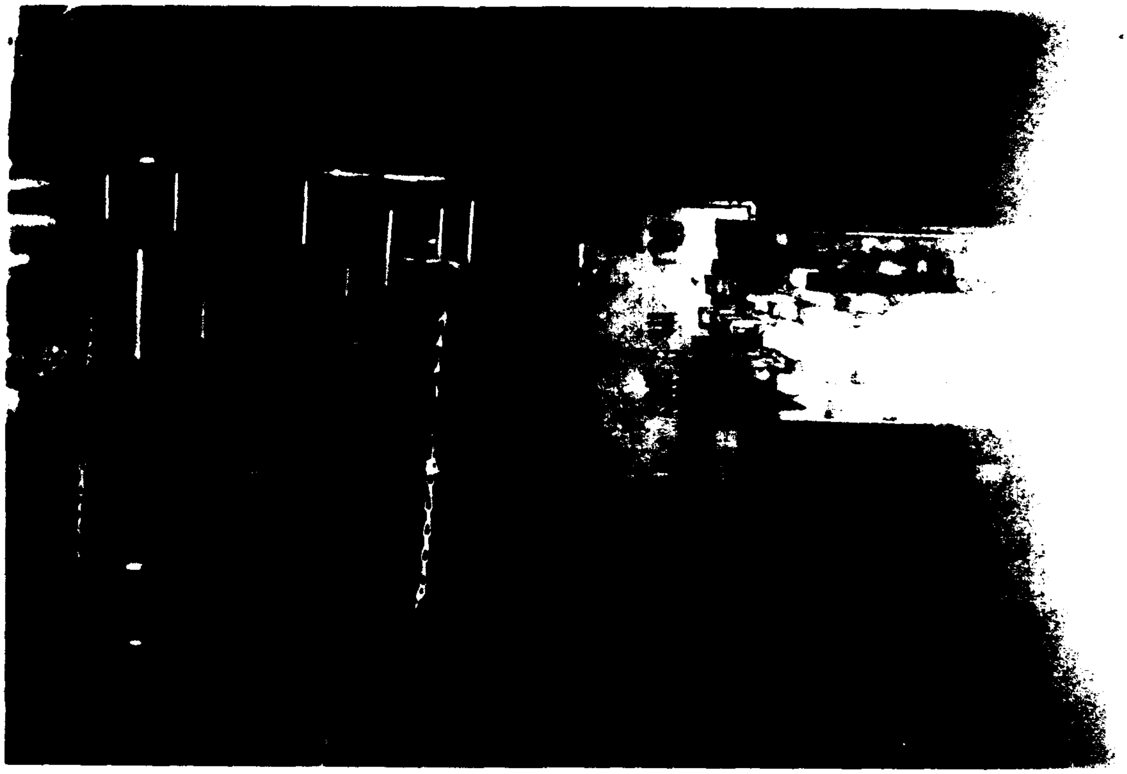


Fig. 7 - Obstructions on the third deck



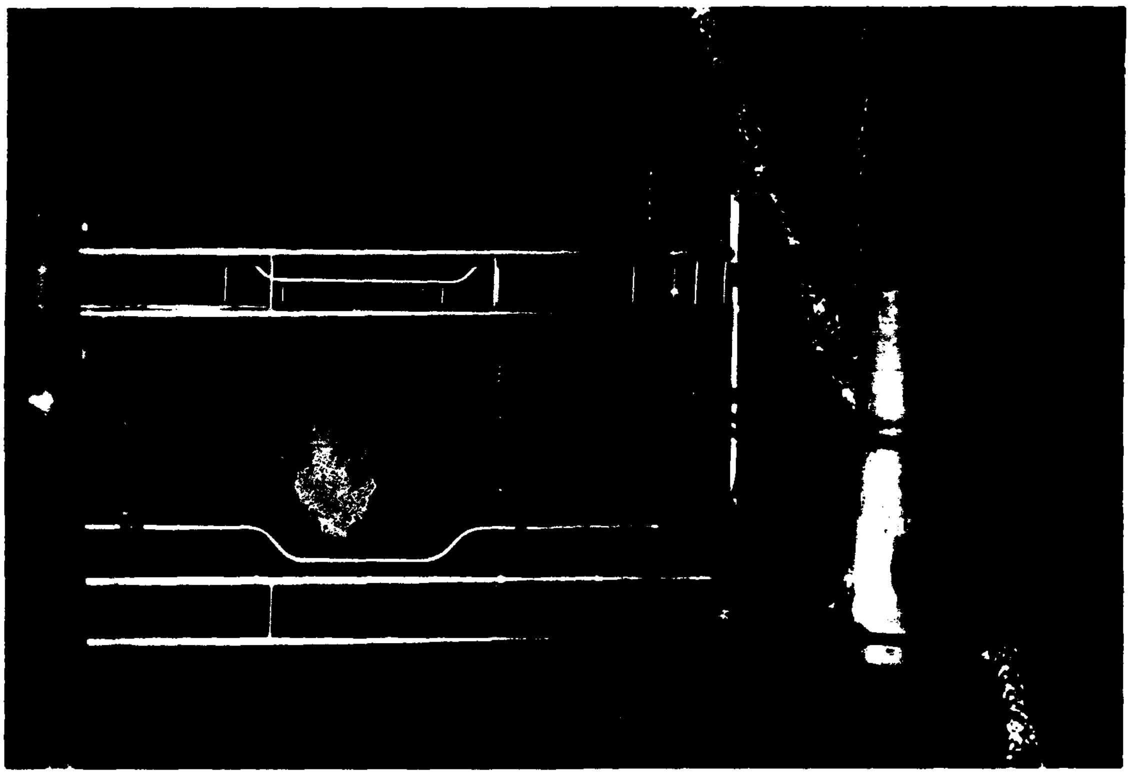


Fig. 8 - Obstructions in Berthing 2

5.2 Ventilation

The ventilation used for these tests was supplied from the ship's ventilation system, TPSS (Total Protection Supply System), and TPES (Total Protection Exhaust System). The supply system is located at 3-16-0-L at FR 21 near the overhead. It has a design flow of 7,645 Lpm (270 cfm). Its measured flow was 7,928 Lpm (280 cfm). The exhaust system has a design flow of 7,645 Lpm (270 cfm) and returned via washroom 3-16-1. The measured flow for this fan was 6,173 Lpm (218 cfm).

The LPSS (Limited Protection Supply System) and LPES (Limited Protection Exhaust System) located in the DDG 51 machinery space was used to supply air to the third deck. Air to the fire was throttled using WTDs 3-22-1 and 3-18-1.

The second deck was exhausted using the ship's fan E1-15-1 via a ventilation duct with F-stop covers. This duct discharged to weather at the 02 Level.

5.3 Fuel Package

Five methanol background burns, designated fd_a1 - fd_a5, were performed prior to the wood crib background burns. These tests were performed to shakedown, calibrate, and adjust instrumentation. Thirty-seven and eight-tenths liters (37.8) (10 gals) of methanol were used in a 91.4 x 91.4 cm (36 x 36 in) pan. The pan was located at 3-18-0.

Four background wood crib burns were performed to establish the Class A threat and investigate the effects of ventilation on the Class A fire, designated fd_bb1 - fd_bb4. The cribs were stacked on a steel stand with an expanded metal platform at 3-17-1, which was connected to a load cell. The number of red oak sticks, which were used for each background test, is shown in Table 1. Red oak was used as the fuel for its long duration and deep-seated burning characteristics. The background tests lasted on the order of 60 minutes.

Table 1. Fuel Load for Background Burns

Test	Stick Configuration		Initiating Fuel
fd_bb1	Top layer:	2 rows of 4 (10.1 x 10.1 x 122 cm (4 x 4 x 48 in.)) spaced 5.1 cm (2 in.) apart	37.8 L methanol (10 gal) in a 91.4 x 91.4 cm (36 x 36 in.) pan
	Mid layer:	7 rows of 8 (5.1 x 5.1 x 61 cm (2 x 2 x 24 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	
	Base layer:	2 - 10.1 x 10.1 x 122 cm (4 x 4 x 48 in.) used to support the crib	
fd_bb2	Top layer:	3 rows of 4 (10.1 x 10.1 x 61 cm (4 x 4 x 24 in.)) spaced 5.1 cm (2 in.) apart	7.56 L methanol (2 gal) in a 91.4 x 91.4 cm (36 x 36 in.) pan
	Mid layer:	9 rows of 8 (5.1 x 5.1 x 61 cm (2 x 2 x 24 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	
	Base layer:	2 - 10.1 x 10.1 x 122 cm (4 x 4 x 48 in.) used to support the crib	
fd_bb3	Top layer:	3 rows of 4 (10.1 x 10.1 x 61 cm (4 x 4 x 24 in.)) spaced 5.1 cm (2 in.) apart	17.9 L methanol (5 gal) in a 91.4 x 91.4 cm (36 x 36 in.) pan
	Mid layer:	9 rows of 8 (5.1 x 5.1 x 61 cm (2 x 2 x 24 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	
	Base layer:	2 - 10.1 x 10.1 x 122 cm (4 x 4 x 48 in.) used to support the crib	
fd_bb4	Top layer:	3 rows of 4 (10.1 x 10.1 x 61 cm (4 x 4 x 24 in.)) spaced 5.1 cm (2 in.) apart	37.8 L methanol (10 gal) in a 91.4 x 91.4 cm (36 x 36 in.) pan
	Mid layer:	13 rows of 8 (5.1 x 5.1 x 61 cm (2 x 2 x 24 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	
	Base layer:	2 - 10.1 x 10.1 x 122 cm (4 x 4 x 48 in.) used to support the crib	

Seven firefighting tests, designated at "fd_fx," were performed with the safety team. Crib #1 was located on the load cell platform at 3-17-1 and crib #2 was located at 3-17-2. The fuel load for the seven background firefighting tests is shown in Table 2.

Table 2. Fuel Load for Firefighting Tests

Test		Description	Initiating Fuel
fd_f1 - fd_f3	crib #1	10 rows of 13 (5.1 x 5.1 x 122 cm (2 x 2 x 48 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	45.4 L of methanol (12 gal) in a 91.4 x 91.4 cm (36 x 36 in.) pan
fd_f4	crib #1	same as fd_f1	
	crib #2	10 rows of 13 (5.1 x 5.1 x 122 cm (2 x 2 x 48 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	15.1 L methanol (4 gal) in a 53.4 cm (21 in.) round pan and 15.1 L (4 gal) in a 63.5 cm round pan
fd_f5	crib #1	same as fd_f1	
	crib #2	10 rows of 13 (5.1 x 5.1 x 122 cm (2 x 2 x 48 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	7.56 L of methanol (2 gal) in a 53.4 cm (21 in.) round pan and 11.4 L (3 gal) in a 63.5 cm round pan
fd_f6	crib #1	same as fd_f1	
	crib #2	10 rows of 13 (5.1 x 5.1 x 122 cm (2 x 2 x 48 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	11.34 L of methanol (3 gal) in a 53.4 cm (21 in.) round pan and 15.1 L (4 gal) in a 63.5 cm round pan
fd_f7	crib #1	same as fd_f1	
	crib #2	10 rows of 13 (5.1 x 5.1 x 122 cm (2 x 2 x 48 in.)) spaced 2.5-3.8 cm (1-1.5 in.) apart	20.79 L of methanol (5.5 gal) in a 58.4 x 83.8 cm (23 x 33 in.) pan

Five firefighting tests with the Navy Personnel, designated as "fd_fx," were performed. The location of the cribs was the same as the background firefighting tests. A standard wood crib fuel load and initiating fuel, equal to the arrangement in fd_f1, was used for both crib #1 and crib #2. The exception was test fd_f10, where 37.8 L (10 gal) of methanol was combined with 4.5 L (1.2 gal) of diesel fuel and 3.0 L (0.8 gal) of heptane for the initiating fire. The intent was to increase smoke production, but the result was not satisfactory.

5.4 Instrumentation

The locations of all the instruments used in the forward test area are shown in Appendix A, Figs. A4 through A9. The Appendix also provides details on instrumentation that was out of service for specific tests. The location of key instruments is described in the following sections.

5.4.1 Thermocouples

Type K, inconel-sheathed, chormel sheathed thermocouples were used to measure compartment air, overhead and structural element temperatures. Thermocouples located on the third deck included the following:

1. Two vertical strings located at FR 3-20-1, Ch 34-40,and FR 3-20-2, Ch 25-31. They were 45.7 cm, 91.4 cm, 137.2 cm, 182.8 cm, 228.6 cm, 274.3 cm, 320.0 cm (18 in., 36 in., 54 in., 72 in., 90 in., 108 in., 126 in.) above the deck.

2. Overhead thermocouples located at FR 3-18-1, Ch 21-22, FR 3-18-2, Ch 19-20, FR 3-21-1, Ch 41-42 and 3-21-2, Ch 32-33, at the heights of 15.2 cm and 45.7 cm (6 in. and 18 in.) below the overhead.

Key thermocouples located on the second deck included:

1. Two vertical strings located at FR 2-20-2, Ch 67-71, and FR 2-21-2, Ch 122-127. The heights above the deck for the string at FR 2-20-2 were 45.7 cm, 91.4 cm, 152.4 cm, 177.8 cm, 248.9 cm, and in the overhead (18 in., 36 in., 60 in., 70 in., 98 in. and the overhead). The heights above the deck for the string at FR 2-21-1 were 45.7 cm, 91.4 cm, 137.2 cm, 182.8 cm, 228.6 cm, and 274.3 cm (18 in., 36 in., 54 in., 72 in., 90 in., and 108 in.).

5.4.2 Heat Flux Meters

Two radiometers (Medtherm Corp. Serial numbers 50908 and 1116851) having a range of 0-56.8 kW/m^2 (0-5 Btu/ft^{2}s) were used to measure the radiative heat flux at FR 3-19-1 viewing the crib and FR 3-19-2 mounted in the overhead at the hatch. Two calorimeters (Medtherm Corp. Serial numbers 71881 and 60209) having a range of 0-227 kW/m^2 (0-20 Btu/ft^{2}s) were used to measure the total heat flux at the same locations as the radiometers. The height of the flux meters viewing the crib was 121.9 cm (48 in.) above the deck. Appendix A provides details on when these devices were in service.

5.4.3 Gas Analyzers

Gas analyzers were used to continuously monitor the oxygen (Beckman model 755), carbon monoxide (Beckman Model 865), and carbon dioxide (Beckman Model 865) gas concentrations. The gas sample lines were located in Crew Living 2 and Crew Living 1. The gas sample lines were located at 3-19-2 and 2-17-2 at 15.3 cm (6 in.) below the overhead and 61.0 cm (24 in.) above the deck. Because of analyzer difficulties, the following gases were not available: third deck oxygen 61.0 cm (24 in.) above the deck, third deck carbon dioxide 61.0 cm (24 in.) above the deck, and second deck carbon monoxide 61.0 cm (24 in.) above.

5.4.4 Ultrasonic Flowmeters

Ultrasonic flowmeters (Controlotron 9000 series) were used to monitor the water flow rates to the firehoses and RAMFANs. Water flow rates were monitored at FP 2-28-1 (Ch 1), FP 2-17-1 (Ch 172), FP 2-11-2 (Ch 4), and FP 1-23-1, (Ch 173).

5.5 Firefighting, Damage Control and Protective Equipment

Standard Navy firefighting, damage control and protective equipment used in this test series included the following:

a. One-piece Navy firefighters ensemble (NSN 8415-01-300-6558) with DC/firefighters helmet (NSN 84515-01-271-8069), anti-flash hood (NSN 8415-001-268-3473) and firefighter's gloves (NSN 8415-01-296-5766).

b. Fireman's rubber boots (NSN 8405-00-753-5940).

c. Engineering coveralls (NSN 8405-01-204-5403).

d. Type A-4 oxygen breathing apparatus (OBA) (NSN 4240-00-616-2857).

e. Oxygen breathing apparatus canisters (NSN 4240-00-174-1365).

f. Helmets lights (NSN 6230-01-285-4396).

g. Anti-flash gloves (NSN 8415-01-267-9661).

h. Type 1, 3.8 cm (1.5 in.) 360 Lpm (95 gpm) vari-nozzles IAW MIL-N-24408 (Feecon plastic model), attached to 3.8 cm (1.5 in.) fabric jacketed hose (NSN 4210-00-255-0234).

i. Hand-held flashlights (NSN 6230-00-270-5418).

j. Chemlights (chemically activated markers) Model 95270-53 manufactured by American Cyanamid.

k. Smoke curtains (NSN 4210-01-306-7826).

l. Smoke blanket (NSN 4210-01-306-7827).

m. Smoke curtain clamps (1H0000-LL-CGA-2487).

n. Tubeaxial (box) fan (NSN 4140-01-272-6060).

o. NFTI (NSN 4210-01-21307310).

p. Water motor fan with and without multipliers (RAMFAN 2000 manufactured by RAM Centrifugal Products).

q. OBA voice amplifier, Model B-181A manufactured by Actron Manufacturing Co., Cleveland, Ohio.

Experimental equipment

a. Grinnell Sprinkler Type D3, 125° No. 39 orifice with a k factor of 10 (55 gpm @ 30 psi) attached to a 1.2 m (4 ft) applicator (Fig. 9).

b. British Water Wall Nozzle (Fig. 10).

c. Gel-pack ice vests.

5.6 Procedures

Prior to each test, the fire area was cleared of all personnel. The ship's operational status during the tests was LEVEL Ia [9]. The designated safety officer during these tests patrolled the forward section of the ship. Two persons were positioned aft of FR 3-22-1 to pour and ignite the fuel and to keep watch on the fire while it burned.

The fire pump was brought on line at 827 kPa (120 psi). The proper ventilation configuration was aligned which included fans and accesses to the spaces. The gas sampling system, data acquisition system, and videos were started.

When the ventilation system was aligned and data acquisition system operating, the test director gave the command to have the fuel poured into the pans located in Crew Living 2 and ignited. Air was throttled via WTD 3-22-1 to regulate the fuel burning rate. The fuel was allowed to burn approximately 20 to 25 minutes before button-up, simulating actual ship procedures. Table 3 shows the ventilation configuration during the fire and just prior to the fire party being called away. When the fire was

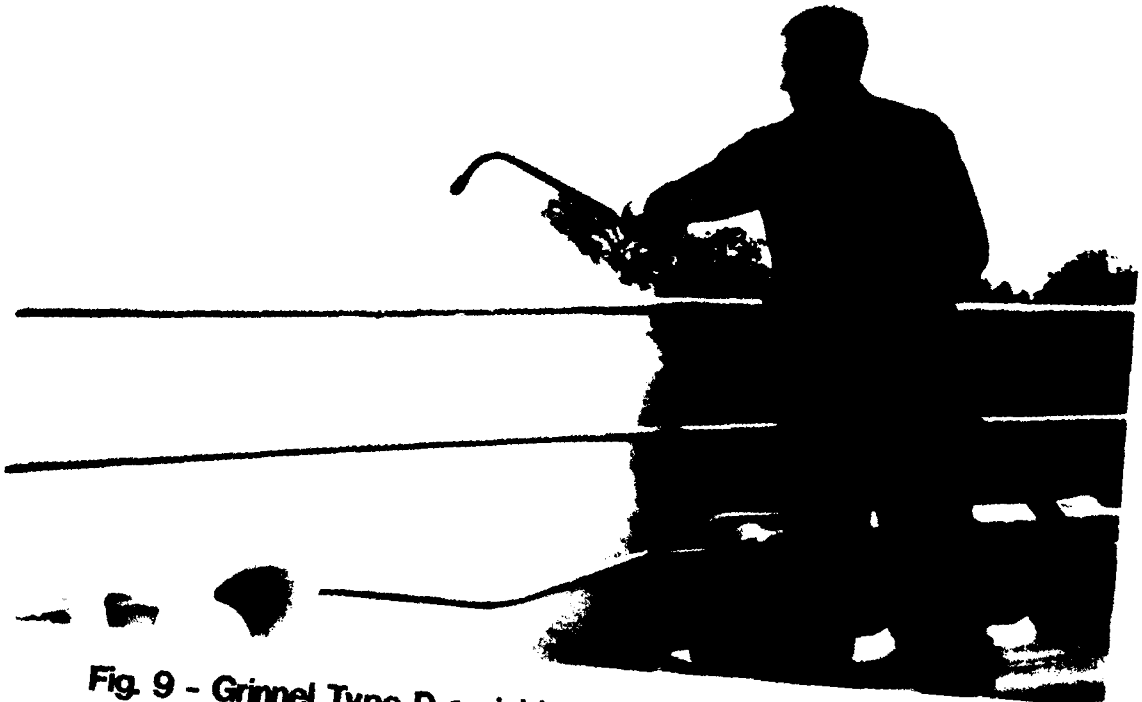


Fig. 9 - Grinnel Type D sprinkler attached to 4 foot applicator

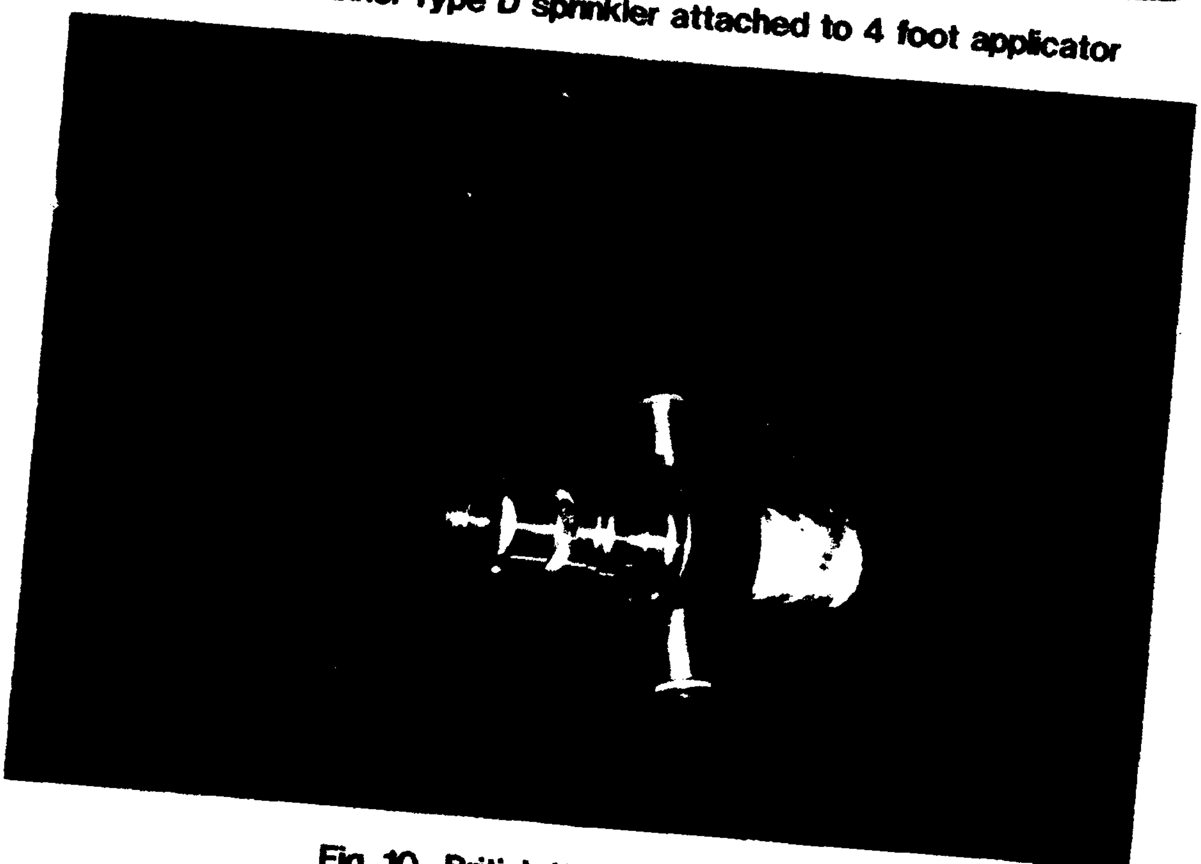


Fig. 10- British Water Wall Nozzle

called away, the inport fire party responding from Repair 2 proceeded to the fire area. The fire party's actions for each of the tests are described in Section 8.

Except as specifically noted, the fire was fought using a 3.9 cm (1.5 in.) hose with a vari-nozzle. The attack team wore full protection using the Navy firefighters ensembles.

Table 3. Ventilation and Closure Settings

Door/Fan	During Fire Ramp-up	Setting Just Prior to Fire Party Called Away
WTD 2-15-3	Closed	Closed
WTD 2-17-1	Closed	Closed or Smoke Curtain
WTH 2-20-2	Open	Closed
WTS 2-21-1	Closed	Closed
WTD 3-22-1	Open	Closed
WTD 3-18-1	Open	Closed
TPSS and TPES	On	Off
LPSS	Low, then High	Low
E1-15-1 Fan	On	Off
F STOP Covers on E1-15-1 Duct	Open	Closed

6.0 EXPERIMENTS CONDUCTED

Table 4 lists the fire science and firefighting tests conducted during the three and one-half week time period of 14 April through 7 May 1993. Firefighting tests fd_f1 through fd_f6 involved the SWOS safety/expert firefighting team. The DC team from the JESSE L. BROWN were the firefighters for Tests fd_f7 through fd_f11. Both teams participated in fd_f12.

The heat threat in the firefighting tests was achieved through the use of one or two wood cribs. Firefighting attack and desmoking procedures were varied to investigate alternative strategies.

Table 5 lists the ancillary research and evaluation performed during the Phase I FDE Tests. These tasks ranged from the very specific, with dedicated instrumentation

Table 4. Fire Science and Firefighting Experiments

Date	Test	Test Team	Threat	Firefighting Tactic	Ventilation/Desmoking Tactic
4/14/93	fd_a1	NRL/HAI	10 gal. methanol	--	Instrument shakedown
4/15/93	fd_a2	NRL/HAI	5 gal. methanol	--	Instrument shakedown
4/17/93	fd_a3	NRL/HAI	10 gal. methanol	--	Close 2-17-1 and activate E1-15-1
4/20/93	fd_a4	NRL/HAI	10 gal. methanol	--	Gas system check
4/20/93	fd_bb1	NRL/HAI	10 gal. methanol + small wood crib	--	Scope wood crib
4/21/93	fd_bb2	NRL/HAI	2 gal. methanol + 2 in. and 4 in. stick wood crib	--	Close hatch; observe effects
4/21/93	fd_bb3	NRL/HAI	Repeat BB2 with 5 gal. methanol	--	Secure HVAC – observe leakage into Berthing 2
4/22/93	fd_bb4	NRL/HAI	1 wood crib	--	Varied ventilation to observe effect of "button-up" and reintroduction of air
4/26/93	fd_a5	SWOS	10 gal. methanol	Walk through	Background for safety team
4/26/93	fd_f1	SWOS	1 crib	Direct attack	WTH 2-20-2 remained open during firefighting
4/27/93	fd_f2	SWOS	1 crib	Direct attack	Smoke curtain over WTH 2-20-2
4/28/93	fd_f3	SWOS	1 crib	Direct attack "water wall" down ladder with vari-nozzle	WTH 2-20-2 open
4/28/93	fd_f4	SWOS	2 cribs	Direct attack	Smoke blanket over WTH 2-20-2; desmoking of Berthing 1
4/29/93	fd_f5	SWOS	2 cribs	Indirect attack with vari-nozzle	Natural venting of Berthing 1
4/30/93	fd_6	SWOS	2 cribs	Aggressive indirect attack	Initially no venting of Berthing 1

Table 4. Fire Science and Firefighting Experiments (Continued)

Date	Test	Test Team	Threat	Firefighting Tactic	Ventilation/Desmoking Tactic
5/1/93	fd_f7	SWOS	2 cribs	Indirect attack with APN/sprinkler	Portable desmoking equipment
5/3/93	fd_f8	DC Team	1 crib	Direct attack	None
5/4/93	fd_f9	DC Team	2 cribs	Direct attack	Active desmoking
5/5/93	fd_f10	DC Team	2 cribs	Indirect attack, then direct attack	Active desmoking
5/6/93	fd_f11	DC Team	2 cribs	Indirect attack, then direct attack	Active desmoking
5/7/93	fd_f12	SWOS/DC Team	2 cribs	British water wall	Vent Berthing 1 as safety precaution

Table 5. Ancillary Research, Testing, and Evaluation

Topic	Research/Program Manager	Organization	Description
Heat Stress	CDR Brad Bennett Dr. Donald Hagen	Naval Health Research Center, San Diego (Code 21)	Investigate modified cool vest; begin evaluation of psychological factors
Emergency Escape Device	Angela Maggiioncala	NAVSSES 045C	Evaluate alternative emergency escape device using ISCC and vertical access trunk areas
Fire Retardant Khakis	LT Bishop	SURFPAC	Evaluate new fire retardant khaki uniform for potential introduction to Fleet; SWOS team member used in one evolution and provided feedback
ISMS	Dick Wyvill Bill Davison	NAVSEA 03R28 NAVSEA 03G	Operate ISMS concurrently with evolution from Repair 2 to DC Central
Communications	Steve Cohen	NSWC 22E	Monitor communications aspects to identify issues, problems, areas of need
WIFCOM	Charlie Doss	NAVSEA	Monitor SHADWELL WIFCOM operations during evolution
Helmet NFTI	Dr. John Hoover	NRL 6184	Evaluate NDI helmet mounted NFTI
Passageway Access	Dennis McCrory	NAVSEA 03G	Evaluate effects of passageway obstructions on access capability
6.3 Sensors	Mickey Thiele	NRL Stennis	Evaluate fiber optic sensors; provide input to ISMS
6.2 Sensors	Henry Whitesel	DTRC 853	Evaluate experimental fiber optic sensors
NDI — Confined Space Rescue	DCCS Elbert Weeden John Taggart	NDI N432F JJMA	Evaluate NDI device for use in vertical rescue of downed personnel
Distributed DC Equipment Locker Stowage	Hank Kuzma	NAVSEA 03G	Continue evaluation of distributed stowage
COSALS	Chuck Grotenroth	NAVSEA 03G	Evaluate COSALS with respect to SHADWELL equipment/setup
DCAMS	Hank Kuzma	NAVSEA 03G	Continue evaluation of DCAMS

(e.g., heat stress tests) to qualitative evaluations (e.g., effectiveness of communications). In many cases, data from the fire test instrumentation was used to provide correlating data (e.g., sensor tasks). Persons interested in the specifics of any particular evaluation are encouraged to contact the researchers, engineers, or program managers listed.

7.0 FIRE THREAT

The goal was to have a hot thermal layer, on the order of 205-427°C (400-800°F) through which the firefighters would descend vertically. In the test plan [8], estimates were made of the ventilation required to support wood crib fires which could create the desired temperatures. It was estimated that ventilation rates twice that provided by the normal HVAC (nominal 270 cfm) were required to create a 1 MW fire, which would result in upper layer temperatures on the order of 200°C. A heat release rate on the order of 4 MW was needed to create upper layer temperatures of 400°C; this would require about 2500 cfm of air (or three full door openings) plus three or four wood cribs of the size used in these tests.

The addition of massive quantities of air contradicts standard Navy firefighting procedure which is to isolate all natural and mechanical ventilation openings when a space has been abandoned. Based on the need to both create a hot fire (with a large quantity of air) and seal the compartment, the procedure described in Section 5.5 was adopted. The fire was "ramped up" using air supplied from the third deck via the watertight access doors. The fire was vented through the hatch, with an exhaust on the second deck via a ship's ventilation fan. Several variations of this air throttling/exhaust were needed to create the optimum heat buildup condition; too much supply air tended to cool the compartment while too little exhaust tended to choke the fire (i.e., the fire became oxygen deficient).

Two Class A fuel loads were used: one and two wood cribs (Figs. 11 and 12). To characterize the threat, the upper compartment temperature of Berthing 2 was monitored 15.2 cm (6 in.) and 45.7 cm (18 in.) below the overhead. Table 6 shows the average temperatures just before the watertight hatch 2-20-2 was closed and also at the time firefighters entered the space. Figures B-5 - B-8 and B-77 - B-80 in Appendix B show representative data for these thermocouples for a one crib fire threat, fd_f3, and a two crib fire threat, fd_f11. The data show that the upper compartment temperature is at or near the maximum just before the hatch is closed. The temperature declines quickly after the hatch is closed and ventilation secured due to oxygen depletion in the space (Figs. B48, B49, B120, and B121).

Table 6 shows that the upper compartment temperatures in Berthing 2 are nearly the same, about 200°C, when firefighters enter the space in both the one and two crib fire tests. This is most likely the result of "self regulating" characteristics of the wood crib. The oxygen drops exponentially, supplied only by leakage to space. At about 12%, the rate of heat release steadies at the same rate as a function of the oxygen available. As a result, the temperatures in the space are nearly the same. References [10] and [11] provides details on this phenomena.

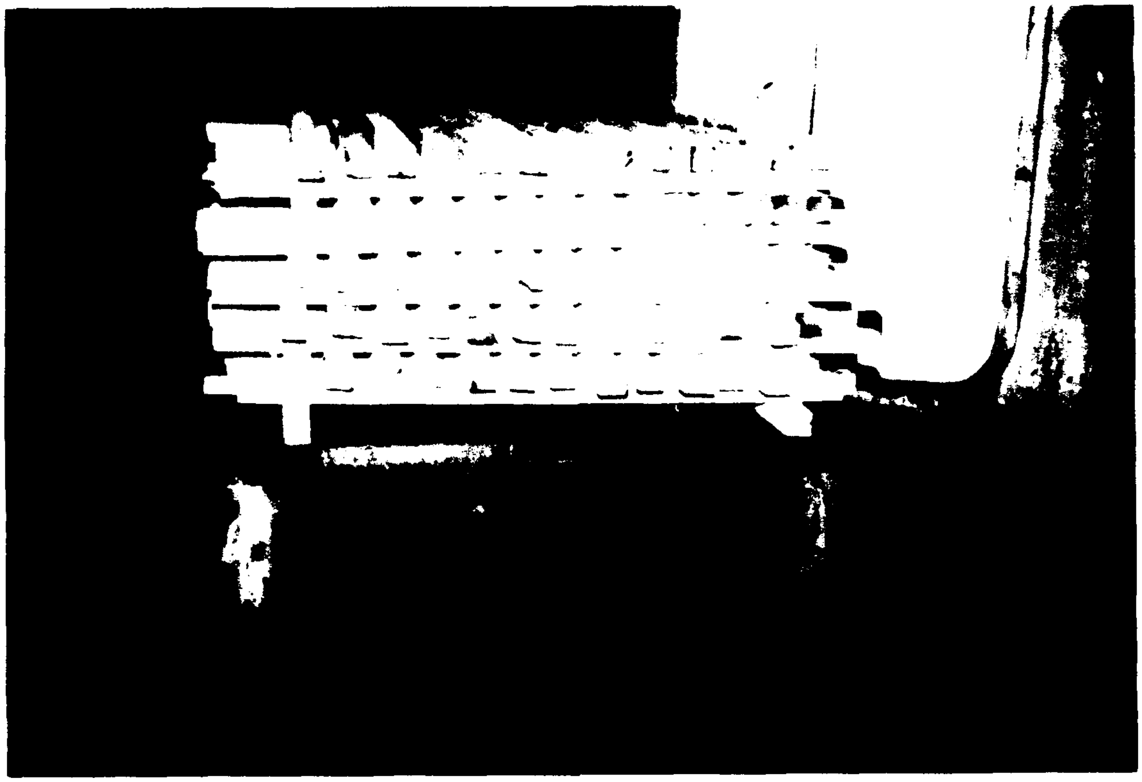


Fig. 11 - One crib set-up

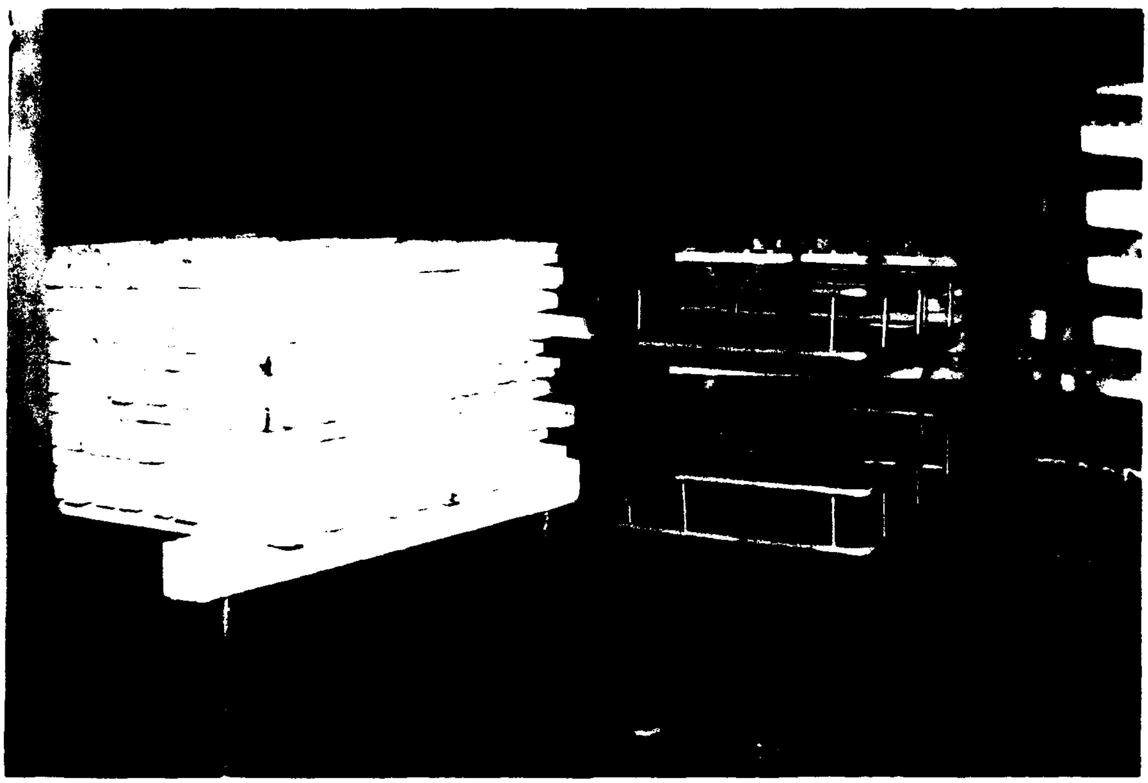


Fig. 12 - Two crib set-up

Table 6. Berthing 2 Upper Compartment Temperatures

Test	Average Temperature* Just Before Hatch and Ventilation Secured (°C)	Average Temperature* at Time Firefighters Entered the Space; Hatch and Ventilation Secured (°C)
One Crib Tests		
fd_f1	298	186
fd_f2	297	227
fd_f3	298	Not identified
fd_f5**	297	182
fd_f8	253	201
Average	287	199
Two Crib Tests		
fd_f4	370	251
fd_f6	337	191
fd_f7	373	220
fd_f9	373	195
fd_f10	336	192
fd_f11	385	216
fd_f12	353	215
Average	361	211

* Average of the four thermocouples at 15.2 cm (6 in.) and the four thermocouples at 45.7 (18 in.) below the overhead.

** Test fd_f5 was a two crib test where the second crib did not fully ignite. For threat purposes, it should be considered as a single crib threat.

In the "buttoned up" situation for a Class A fire, the upper compartment temperature is not a very good predictor of the threat. Qualitatively, the firefighters indicated that the two crib fires were hotter. The additional heat results from bulkhead radiation (Berthing 2 bulkhead temperatures are higher, Figs. B9, B10, B13, B14, B82, B83, B86, B87), higher temperatures in Berthing 1 (See Section 8, Figs. 13-24), and higher average temperature in Berthing 2 (see Section 8).

The heat release rate estimated for a single wood crib was 1.9 MW based on an average mass loss rate of 0.11 kg/s (14 lb/min) and a heat of combustion of 8,438 kJ/kg (8000 Btu/lb). The predicted temperature of approximately 300°C (572°F) is in excellent agreement with the results (average 287°C (549°F)). For two cribs, the predicted temperature was 400°C (752°F) for a 3.8 MW fire. The actual average was 362°C (684°F). This indicates that the two cribs were underventilated, or more likely, that the ventilation configuration resulted in reduced burning efficiency.

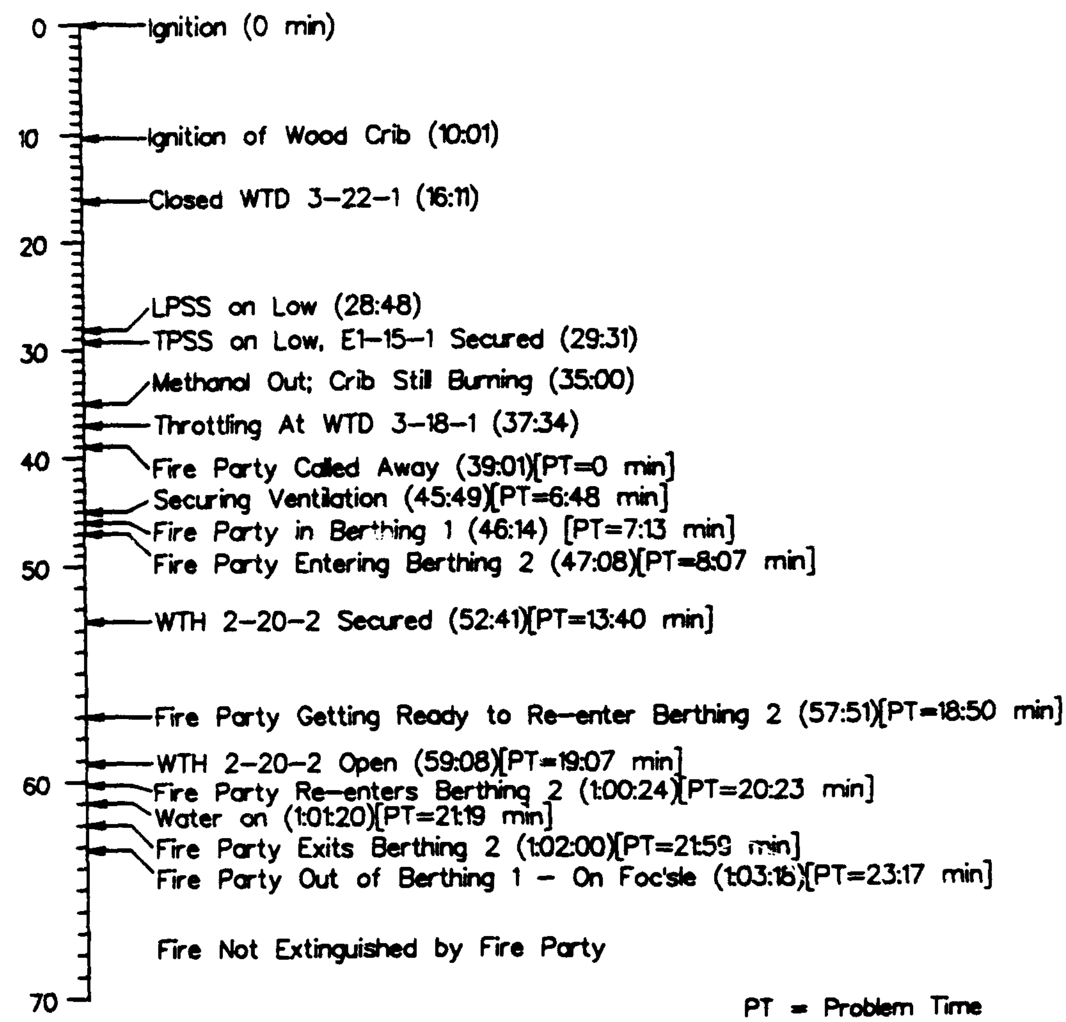
8.0 RESULTS OF FIREFIGHTING TESTS

8.1 General Test Results

The results of the Phase I firefighting tests are documented in this section. The principle variables for each test were identified in Table 4. For each test, there is a brief description of the evolution, a time line of activities, and data graphs showing the average temperatures (average of all thermocouples on the string) in Berthing 1 and Berthing 2. Representative data for all data channels are given for the one crib threat (Test fd_f3) and two crib threat (Test fd_f11) in Appendix B. Specific comments related to doctrine, tactics, procedures, equipment, communication, and training are described in Section 8.2. Specific comments related to desmoking, venting, and indirect attack are described in Section 9.

fd_f1. Firefighters entered the space via the WTH 2-20-2 after working in Berthing 1 for 15-20 minutes. As a result, they were already tired and were not fresh. They entered the space and used a direct, short burst firefighting attack. After the first burst of water, the nozzleman had to use an emergency exit on the third deck. The nozzleman was the person who had to raise the hatch to access the space. As a result, he already was fatigued before the direct attack was initiated. No difference in terms of heat threat were noticed between the front and rear of the nozzle team. The nozzleman suggested that an access team should be used to access the space, to keep the hose team fresh. There were no specific desmoking actions during this test. Table 7 shows the sequence of events for this test. Figure 13 shows the average temperatures in Berthing 1 and 2.

Table 7. – Timeline of Events for fd_f1



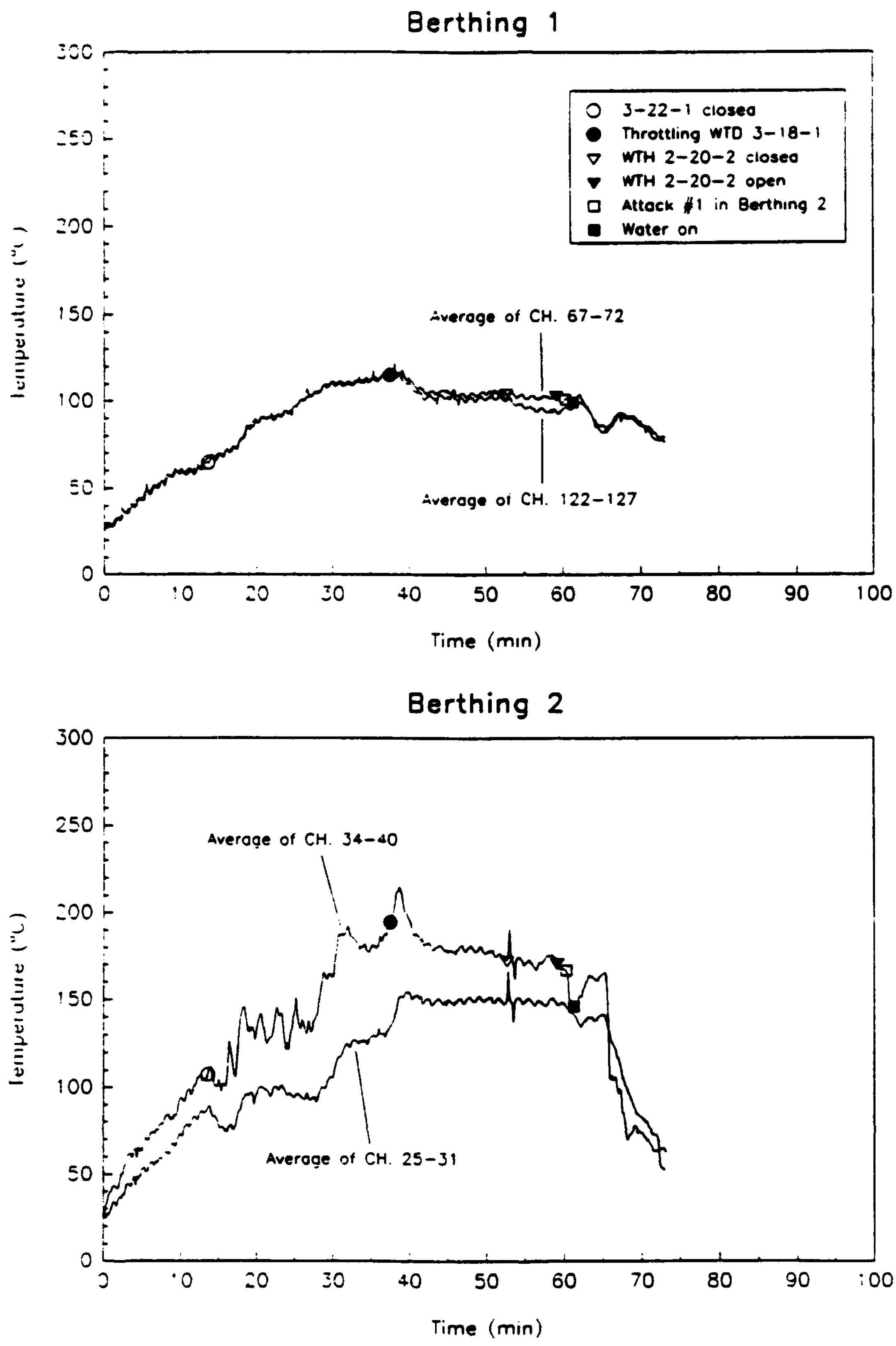
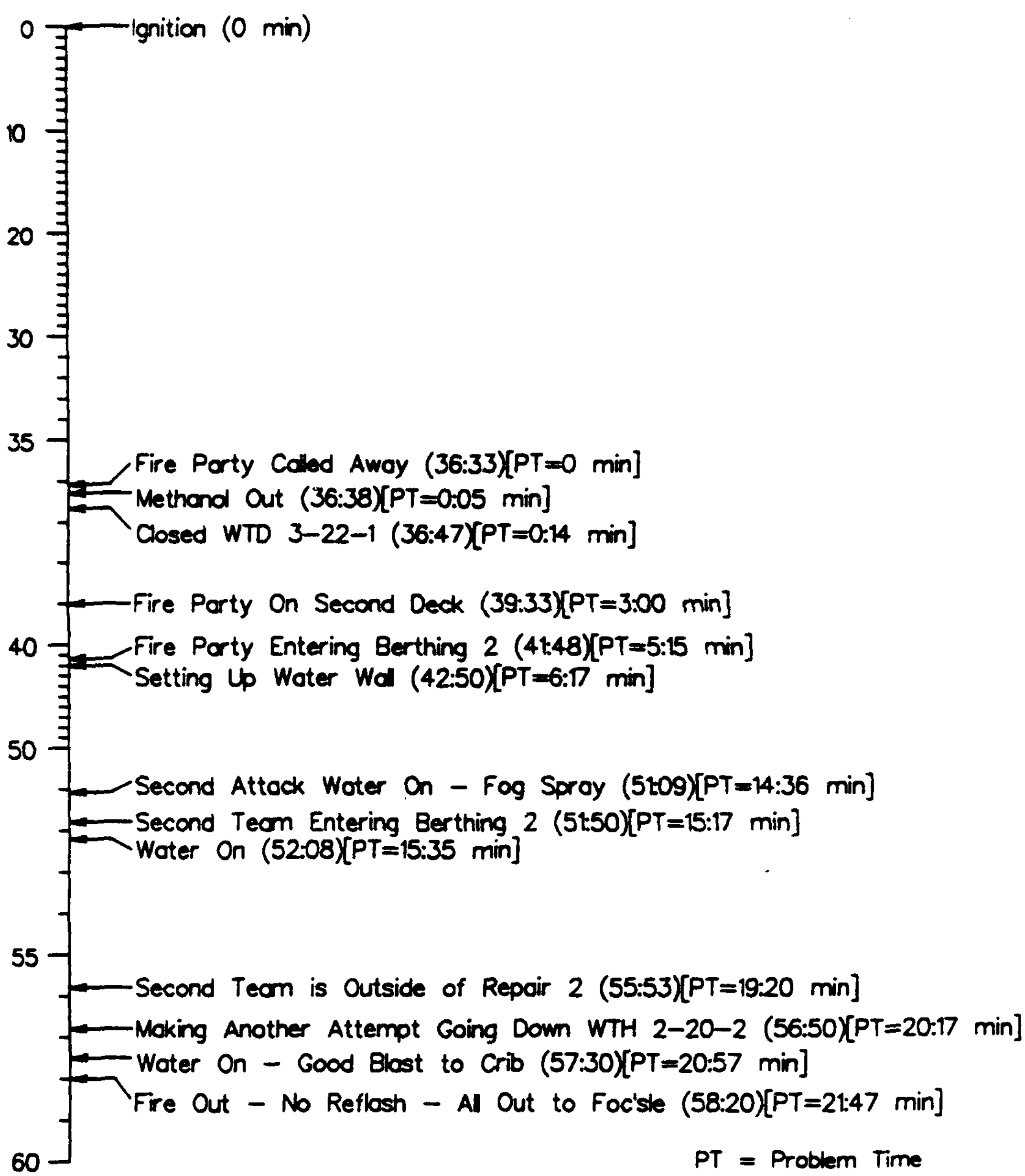


Fig. 13 – Average temperatures in Berthing 1 and 2, fd_f1

fd_f2. This test was a repeat of fd_f1. On the first attack, seven gallons of water were used with one quick burst. The firefighting team was driven out of the space. On the second attack, a backup firefighter used a water fog pattern while entering down the ladder. Eventually, the firefighting team was driven out of the space. A third direct attack was made. Firefighters attacked the fire for a total of 8.5 minutes on the second and third attacks. There were no specific desmoking actions during this test. Table 8 shows the sequence of events for this test. Figure 14 shows the average temperatures in Berthing 1 and 2.

Table 8. – Timeline of Events for fd_f2



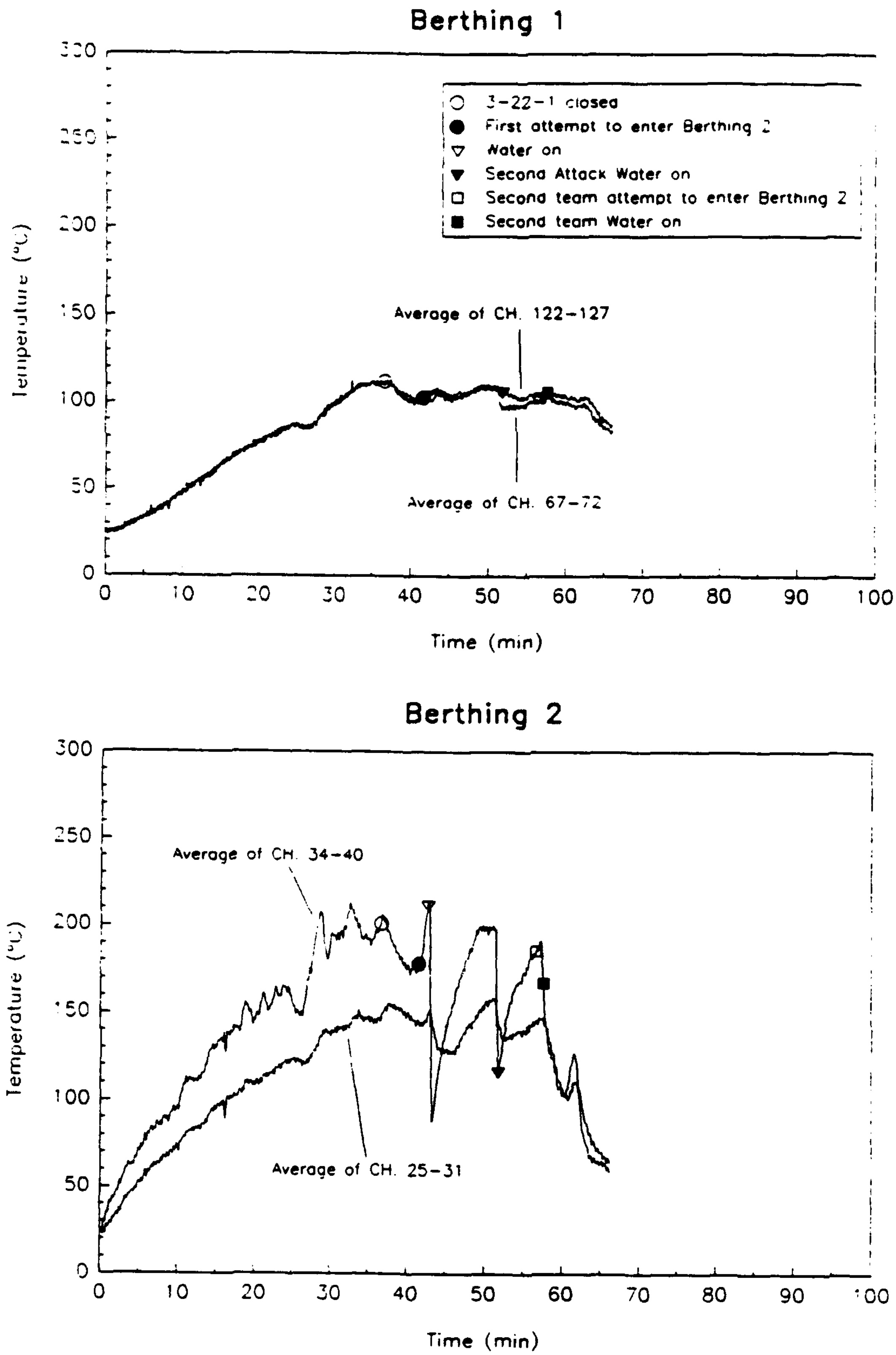
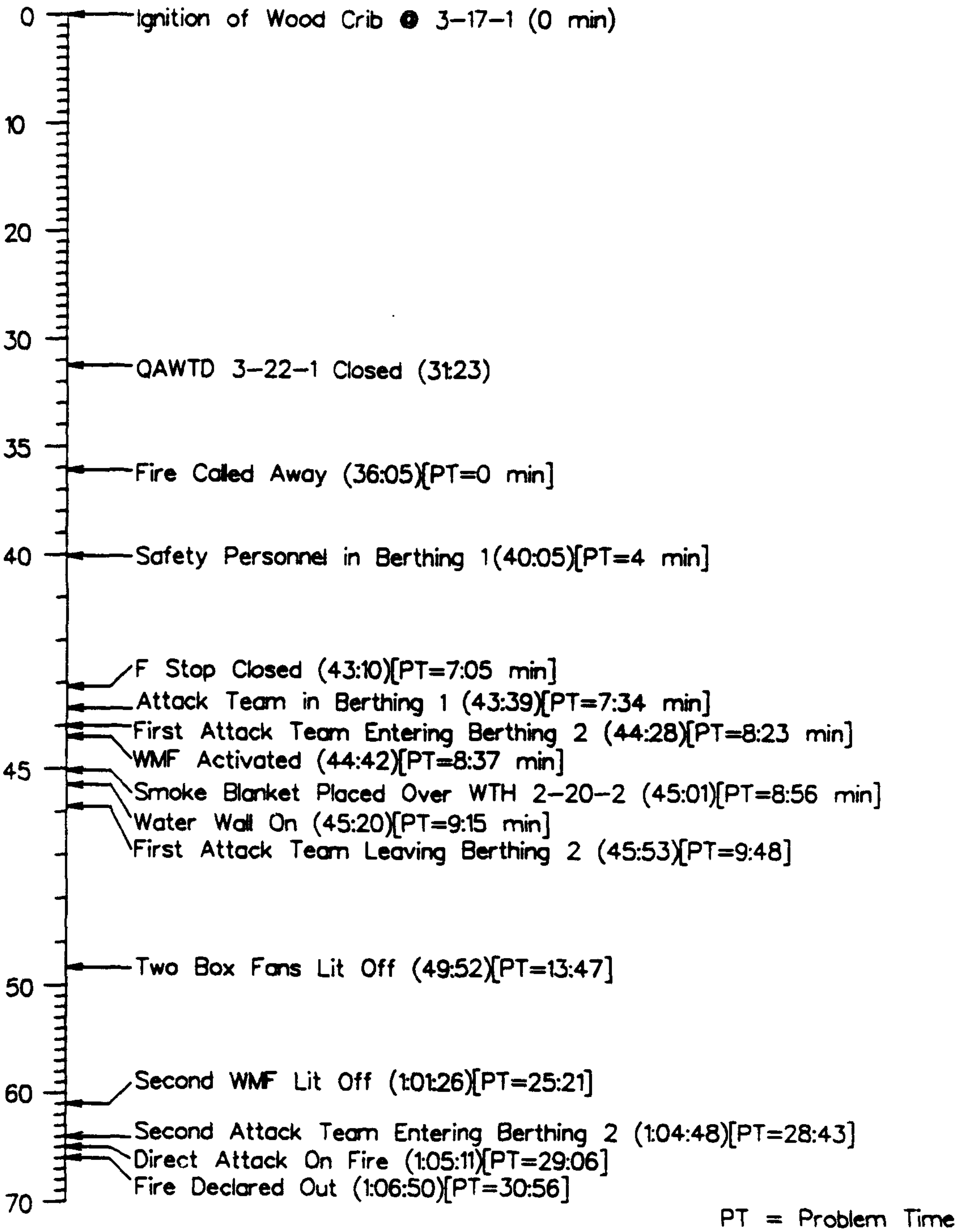


Fig. 14 – Average temperatures in Berthing 1 and 2, fd_f2

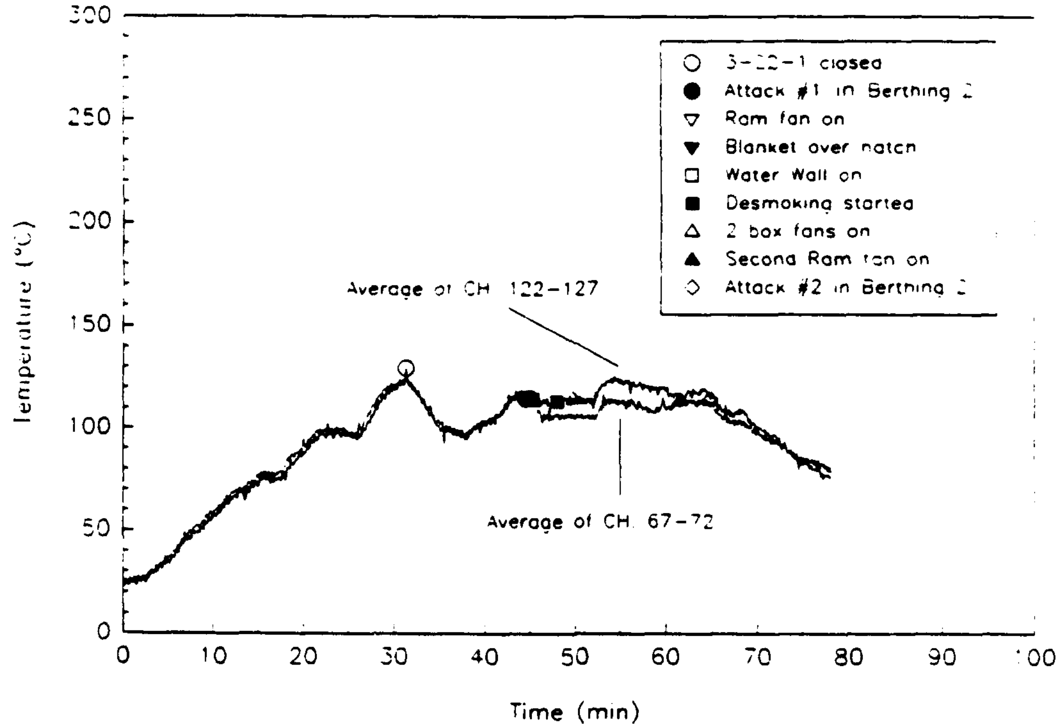
fd_f3. This test was a direct attack where the firefighters used a "water wall" as they entered down the ladder. The vari-nozzle was used on a 70° fog for the initial attack. The nozzleman had trouble with his OBA bags and had to exit the space. The backup nozzleman used a direct attack for five seconds, but steam burns to his wrist and fingers caused him to exit the space. The firefighting team could not get a straight stream pattern on the nozzle. A second attack was initiated using short bursts of 90° fog and straight stream. The scuttle (WTS 1-19-2) in the Shipfitter's Shop was opened during the evolution. One observer on the second deck indicated that there was a "volcano effect" when this scuttle was opened and steam rushed out through the scuttle.

After the first direct attack, WTH 2-20-2 was covered with a smoke blanket. Then the WTS 2-21-1 was opened and a RAMFAN turned on taking suction from the scuttle opening in the Shipfitter's Shop. At this time, there was a solid plume of smoke coming through WTS 2-21-1. Before the second direct attack, the WTS 1-19-2 in the Shipfitter's Shop was opened. The firefighters commented on the good visibility and the fact that the smoke was following the path that had been established. Table 9 shows the sequence of events for this test. Figure 15 shows the average temperatures in Berthing 1 and 2.

Table 9. – Timeline of Events for fd_f3



Berthing 1



Berthing 2

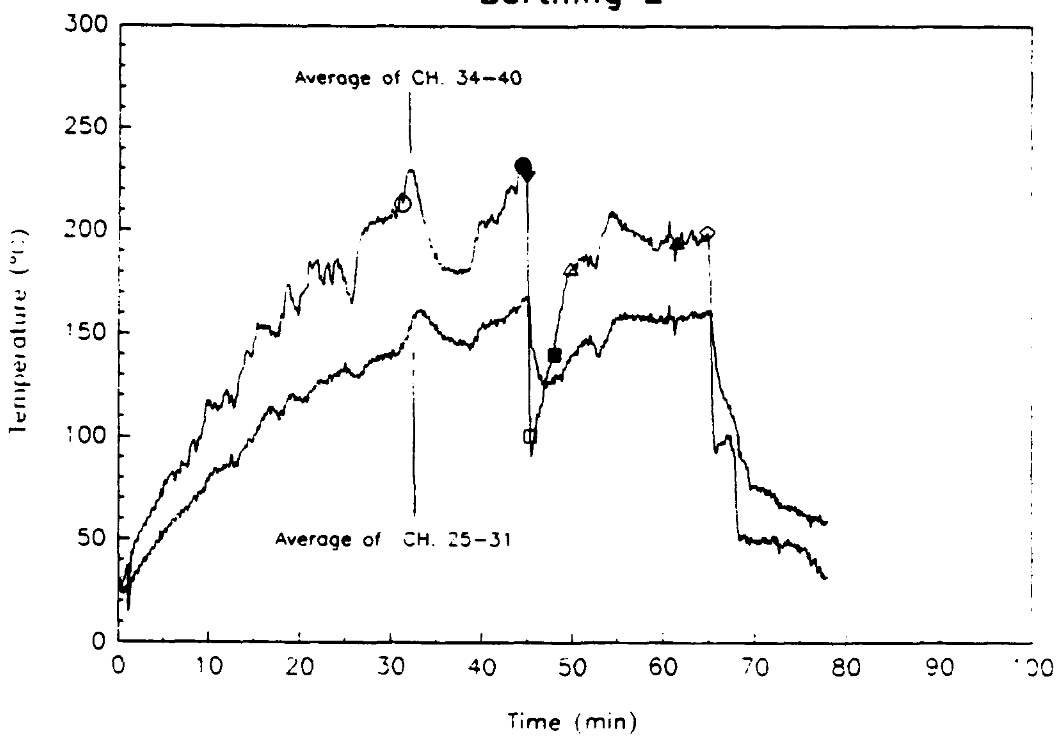
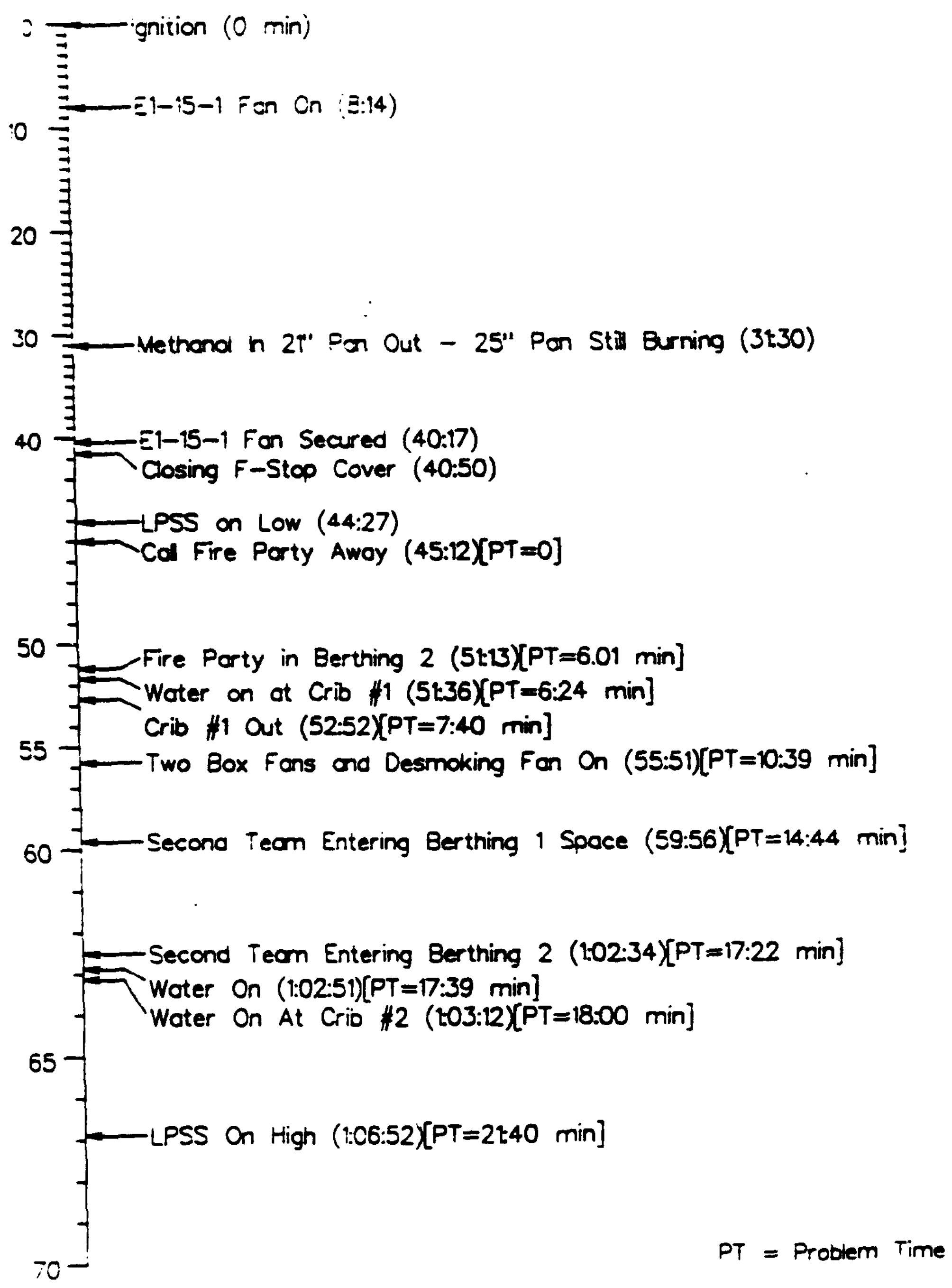


Fig. 15 – Average temperatures in Berthing 1 and 2, fd_f3

fd_f4. This test was used to re-establish the baseline threat using two wood cribs. Normal air supply and return to the space were left operating during the test. The RAMFAN at WTS 1-19-2 was used to ventilate the Berthing 1 area. A smoke blanket was placed over WTH 2-20-2 to contain heat and smoke within Berthing 2. The first attack team went down the ladder and used short water bursts to attack the fire. There was a significant steam build-up. Wide angle and straight stream short bursts were used to attack the fire. A backup nozzleman used a ten-second water burst to attack the fire and was saturated with steam nearly instantaneously. All personnel suffered steam burns, and backup personnel on the second deck noticed the smoke blanket on the hatch puffing as water was applied to the fire. The attack team indicated that there was nowhere to escape from the steam. After exiting the space, a second attack team reentered the space and attacked the fire for three to four minutes. They indicated that the steam was not too bad.

Before the first attack team entered Berthing 2, WTS 2-21-1 in Berthing 1 and WTS 1-19-2 in the Shipfitter's Shop were opened. After the first direct attack on crib #1, a box fan in the starboard passageway door (WTD 2-22-1) was turned on, a RAMFAN at the scuttle (WTS 1-19-2) in the Shipfitter's Shop was turned on, and a second box fan on the main deck was turned on to help push the smoke out of the Shipfitter's Shop. Table 10 shows the sequence of events for this test. Figure 16 shows the average temperatures in Berthing 1 and 2.

Table 10. - Timeline of Events for fd_14



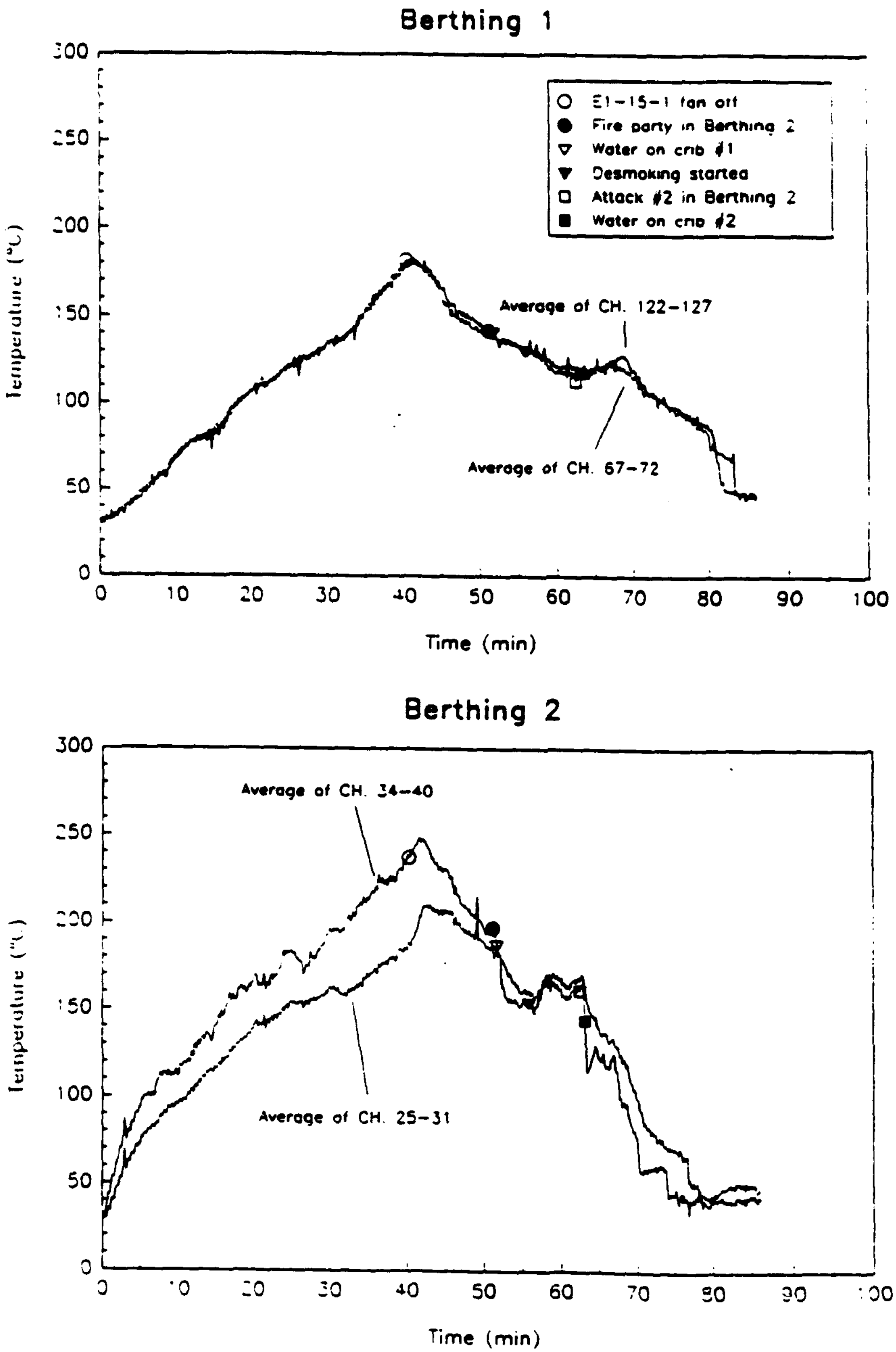
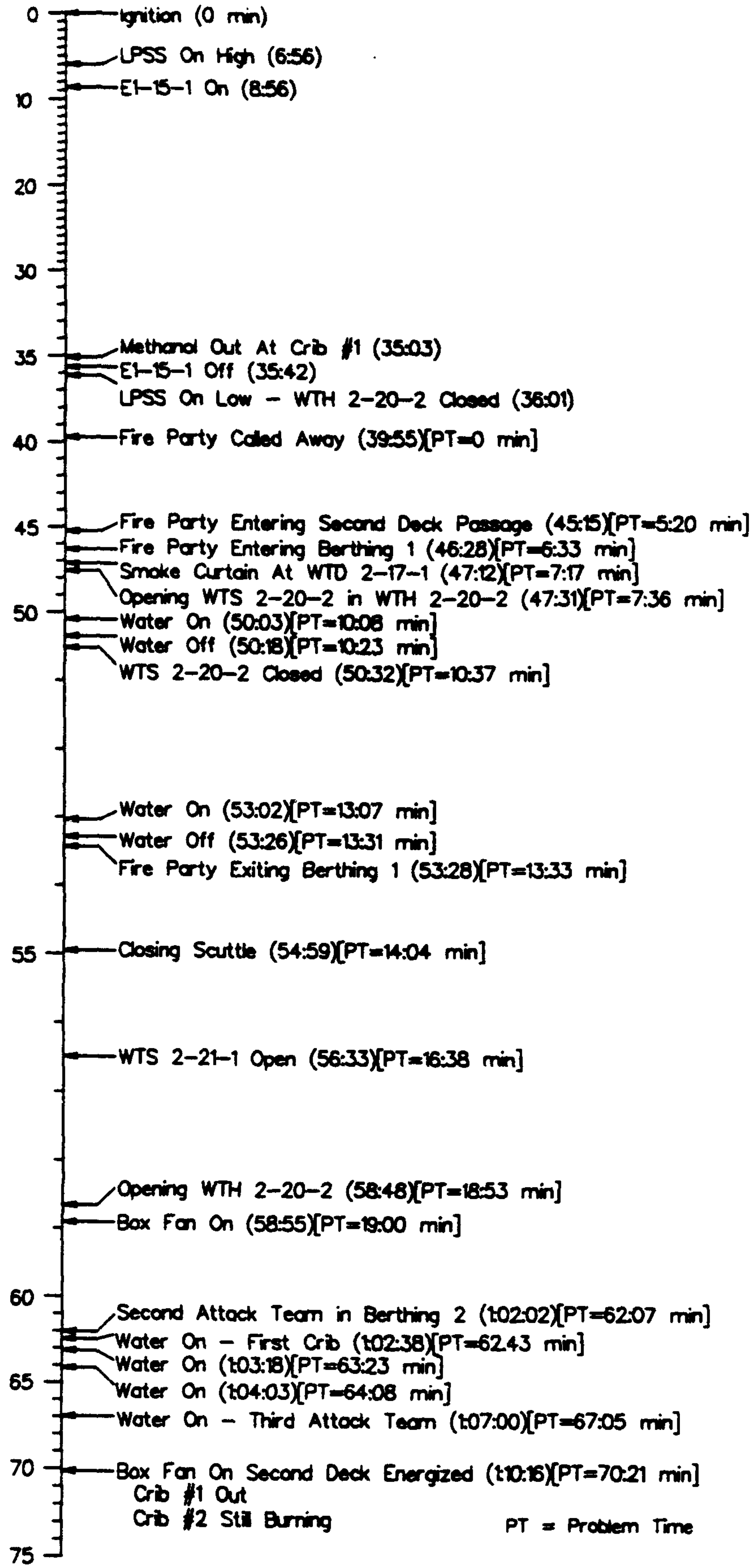


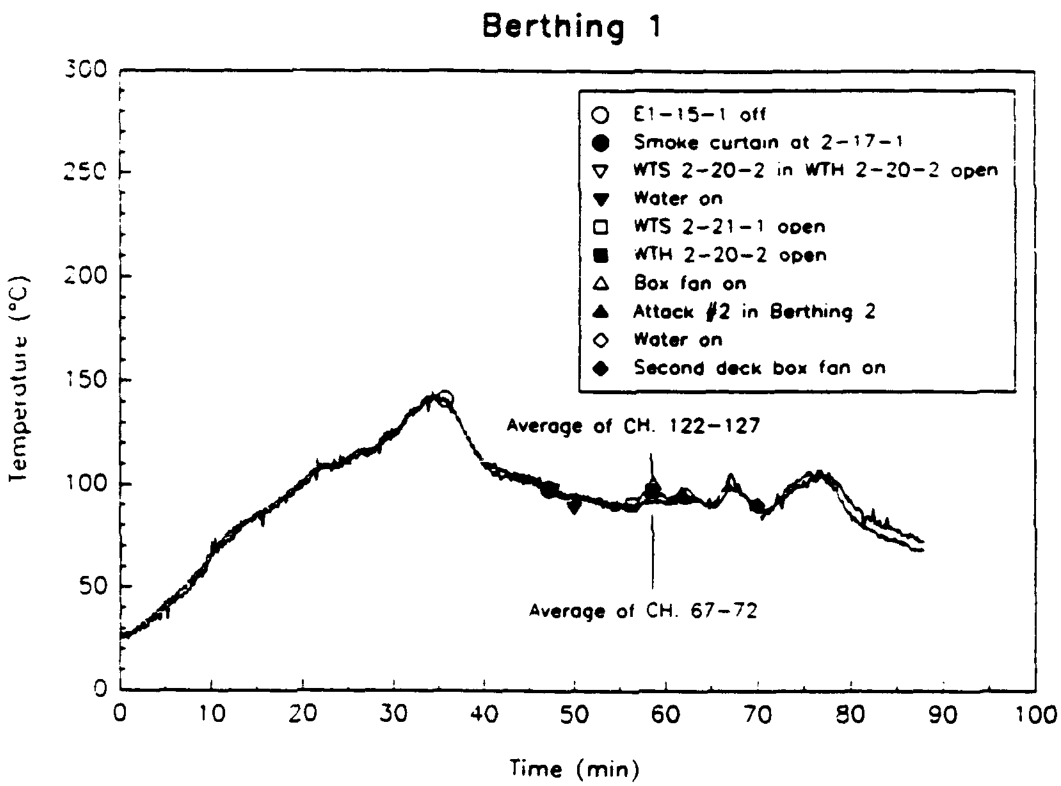
Fig. 16 — Average temperatures in Berthing 1 and 2, fd_f4

fd_f5. This test was an indirect attack on a two crib fire using natural venting techniques. Because the second wood crib did not ignite and sustain active burning, this threat was more like a one crib fire threat. A smoke curtain was staged over the scuttle at WTH 2-20-2. The firefighters entered Berthing 1 and used an indirect attack with the vari-nozzle through the open scuttle area. WTS 1-19-2 was open to vent Berthing 1 naturally to weather via the Shipfitter's Shop. Firefighters used a five-second burst, 26 ℓ (7 gal) of water on the initial attack. A second indirect attack lasted for 24 seconds where 148 ℓ (40 gal) was used; 174 ℓ (47 gal) total for the indirect attack. The firefighters noted that there was a venturi effect when the vari-nozzle was placed at the scuttle—it tended to suck the smoke blanket down toward the space. Direct attack was mounted after the second indirect attack. Firefighting personnel found the space to be tenable, with a minimum of manpower and equipment needed to conclude the extinguishment. They indicated that the indirect attack provided a cooler space.

As the firefighters descended to the Repair 2 area, WTS 1-19-2 in the Shipfitter's Shop was opened. After the first indirect attack, WTS 2-21-2 was opened to allow the firefighters to access Berthing 2. The conditions in Berthing 1 and on the second deck in general were very poor. The smoke and steam coming from Berthing 2 seemed to settle on the second deck instead of venting to weather through WTS 1-19-2 in the Shipfitter's Shop. Table 11 shows the sequence of events for this test. Figure 17 shows the average temperatures in Berthing 1 and 2.

Table 11. – Timeline of Events for fd_f5





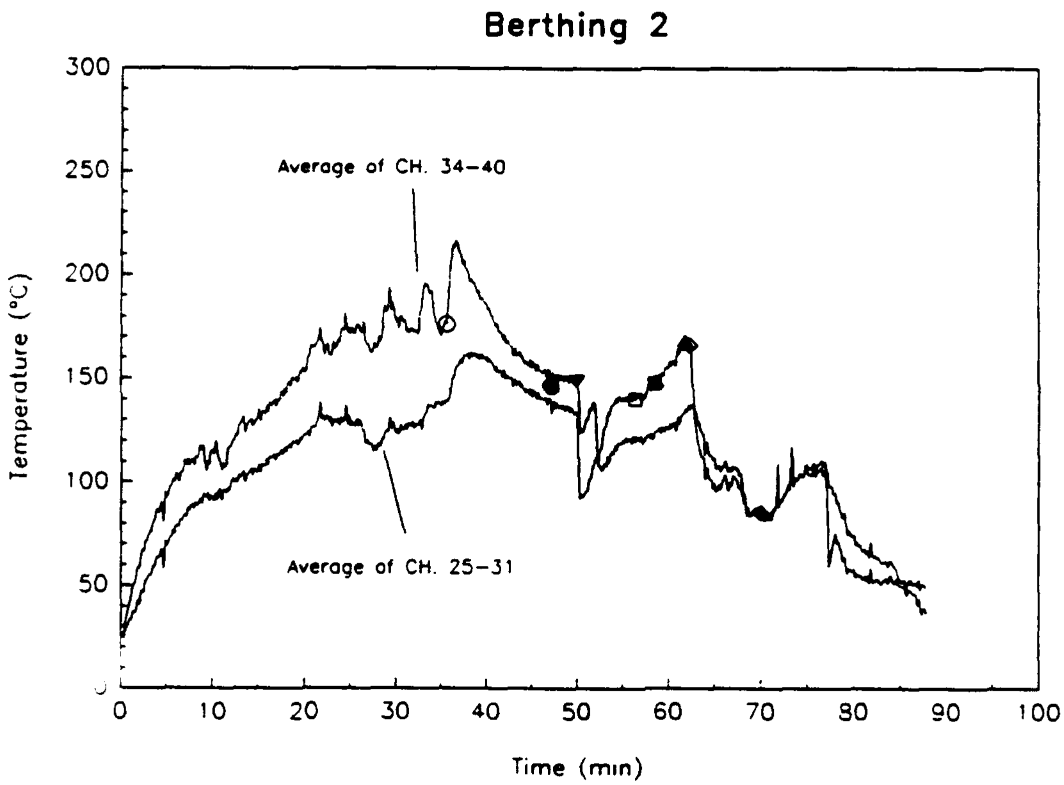
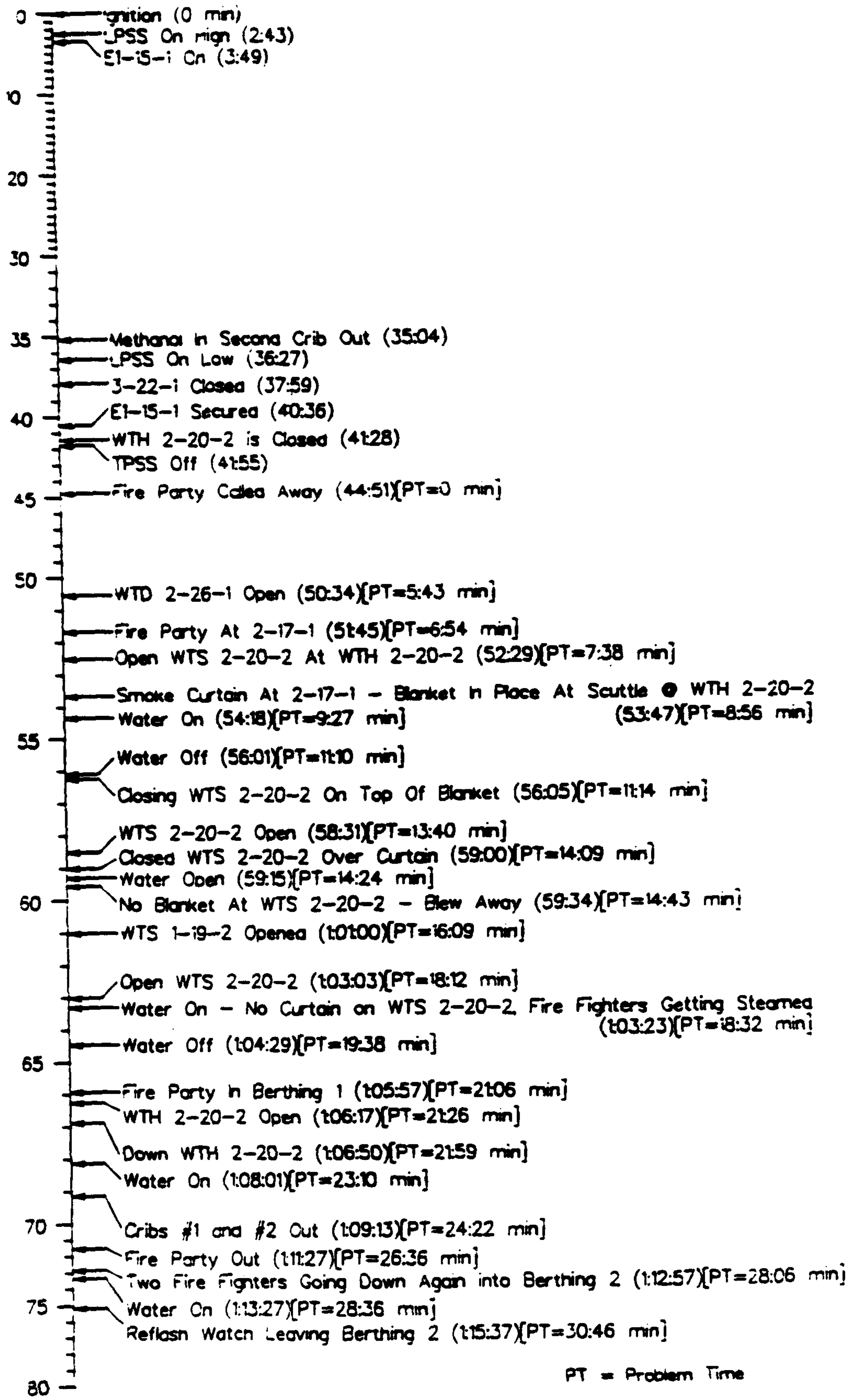


Fig. 17 — Average temperatures in Berthing 1 and 2, fd_f5

fd_f6. This was a two crib test, repeating the tactics in fd_f5 except that there was no initial venting of Berthing 1 and a more aggressive indirect attack was used. Bunks were added to the Berthing 2 space to provide obstructions. The first indirect attack on Berthing 2 was performed with Berthing 1 "buttoned up." Indirect attacks were performed through the scuttle in WTH 2-20-2. The vari-nozzle on the first indirect attack was used to apply 511 ℓ (135 gal) of water. After the first indirect attack, WTS 1-19-2 was opened, and a smoke/heat management path was provided to weather in the Shipfitter's Shop. The second indirect attack lasted 45 seconds, where 246 ℓ (65 gal) were used for a total of 757 ℓ (200 gal) for the first and second indirect attacks. After the second indirect attack, the firefighting team was forced to leave Berthing 1. A backup team entered Berthing 1 and performed the third indirect attack for about 1 minute, using 397 ℓ (105 gal) of water. In the third indirect attack, steam was observed weeping out of the knife edge of the hatch. Personnel standing by the hatch, particularly on the forward side, were subjected to a substantial amount of steam. They did observe that the space was cooler after the scuttle in the Shipfitter's Shop was opened. The direct attack was mounted, and the steam was not very heavy in Berthing 2. Crib number 1 was still burning, and there was approximately 2.5 cm (1 in.) of water on the deck. The attack team used two bursts of water, using 155 ℓ (41 gal) and 148 ℓ (39 gal) respectively on these two direct attacks. They were relieved by a backup team which used another 105 ℓ (28 gal) to extinguish the fire (1,561 ℓ (413 gal)) of water total used on this test).

Before the first indirect attack, a smoke blanket was placed over WTH 2-20-2. After the second indirect attack, WTS 1-19-2 was opened and a box fan activated on the second deck starboard passageway. The firefighters noticed a decrease in temperature. After the third indirect attack, a box fan located at WTS 1-19-2 and a box fan at WTD 1-15-1 were activated to draw the smoke and steam out of Berthing 1. Table 12 shows the sequence of events for this test. Figure 18 shows the average temperatures in Berthing 1 and 2.

Table 12. – Timeline of Events for fd_16



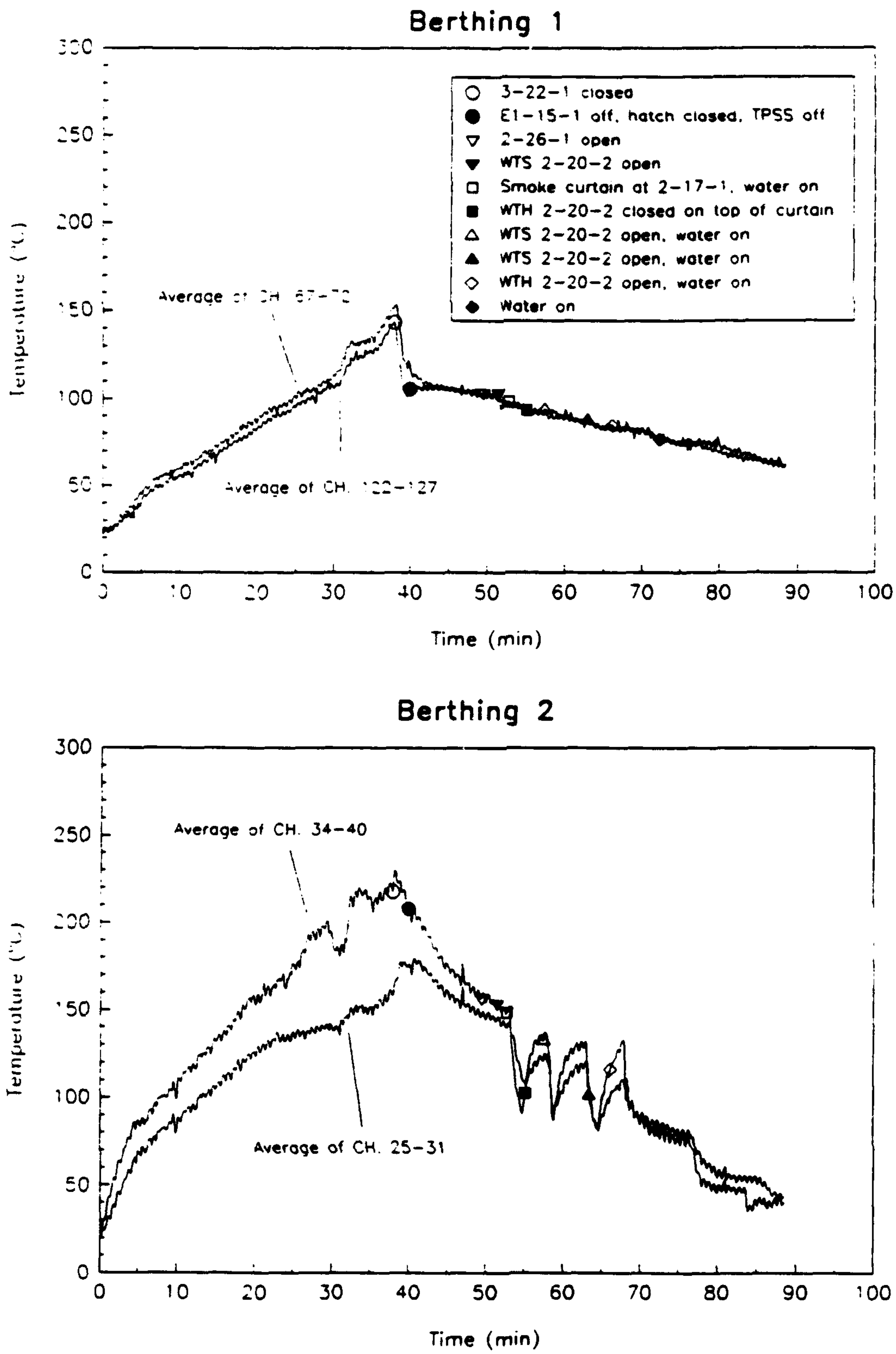
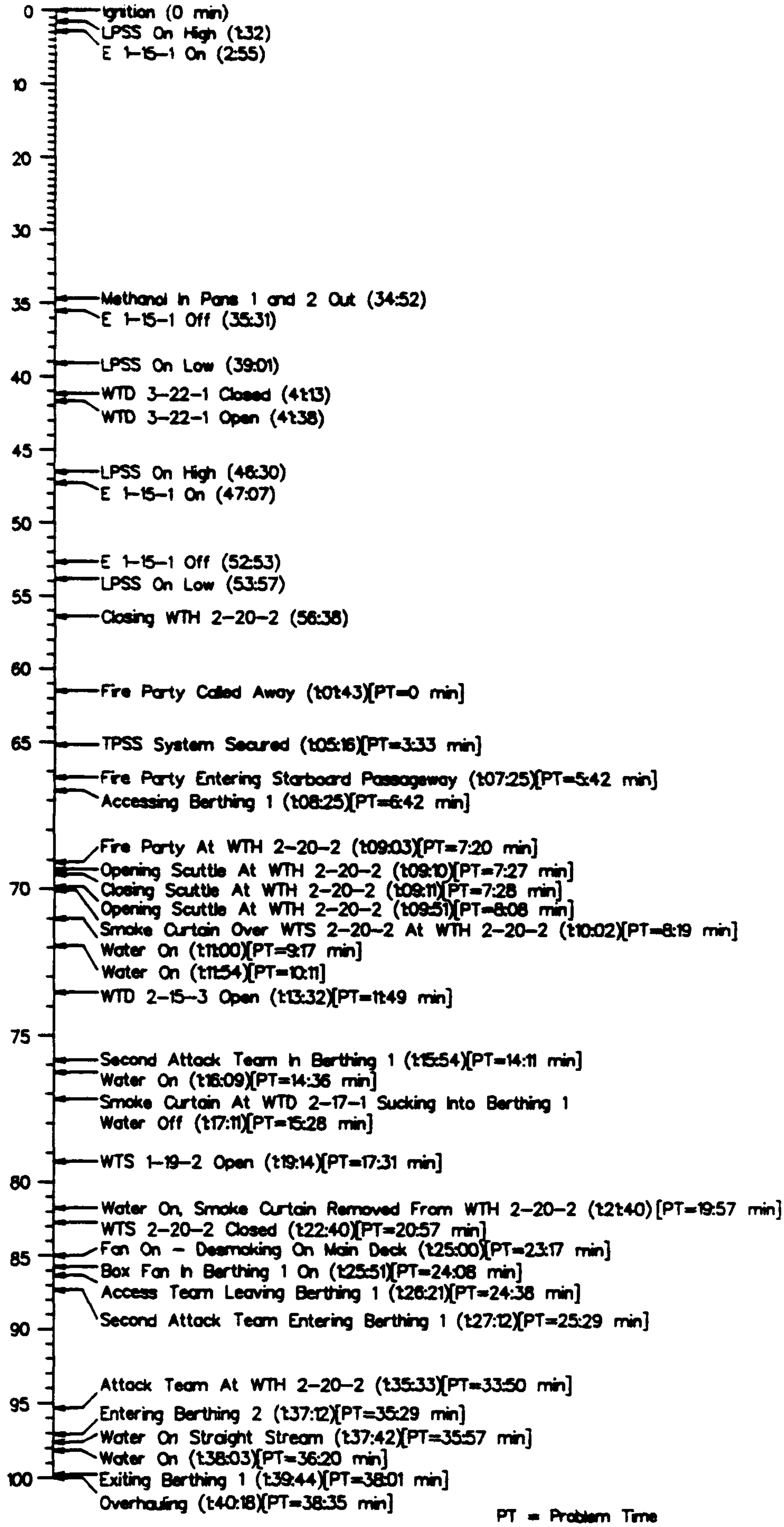


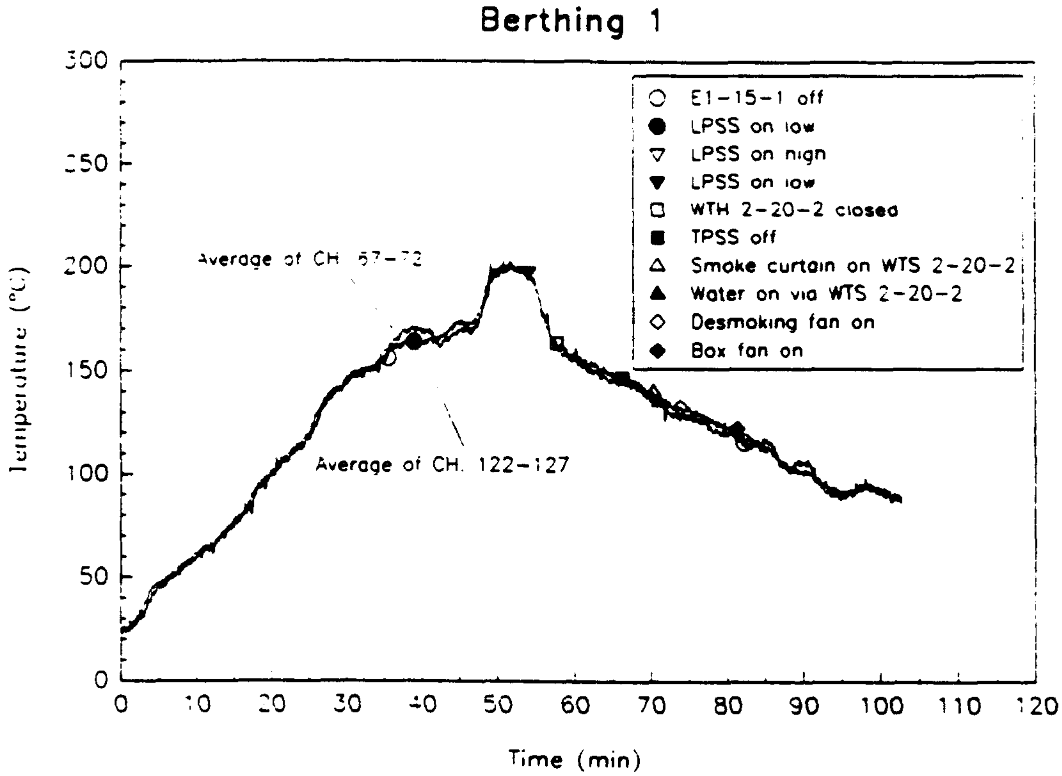
Fig. 18 — Average temperatures in Berthing 1 and 2, fd_f6

fd_f7. This was a repeat of fd_f6 except that the Navy all-purpose nozzle fitted with a sprinkler attachment was used for the indirect attack. The indirect attack lasted one minute and used approximately 318 ℓ (84 gal) of water. The vent path was then opened to weather via the starboard passageway on the second deck. The second indirect attack lasted one minute and used 242 ℓ (64 gal), (636 ℓ (168 gal) total for the first two attacks). The third indirect attack again lasted about a minute and used 231 ℓ (61 gal) (867 ℓ (229 gal) total used on the indirect attack). A direct attack was then mounted using the vari-nozzle. Access was via WTH 2-20-2. 220 ℓ (58 gal) of water were used in a straight stream, direct attack. It was again noticed that the forward side of the hatch on the second deck was the hot side, with the aft side not as hot. Personnel working on the forward side of the hatch had to exit after the first indirect attack. There was substantial steam in the starboard passageway before the passageway was totally vented to weather.

The desmoking actions taken before the first indirect attack included opening WTS 2-21-1 in Berthing 2. After the second indirect attack, WTS 1-19-2 was opened. After the third indirect attack, a box fan on the main deck was turned on to help draw the smoke out of Berthing 1. Table 13 shows the sequence of events for this test. Figure 19 shows the average temperatures in Berthing 1 and 2.

Table 13. – Timeline of Events for fd_f7





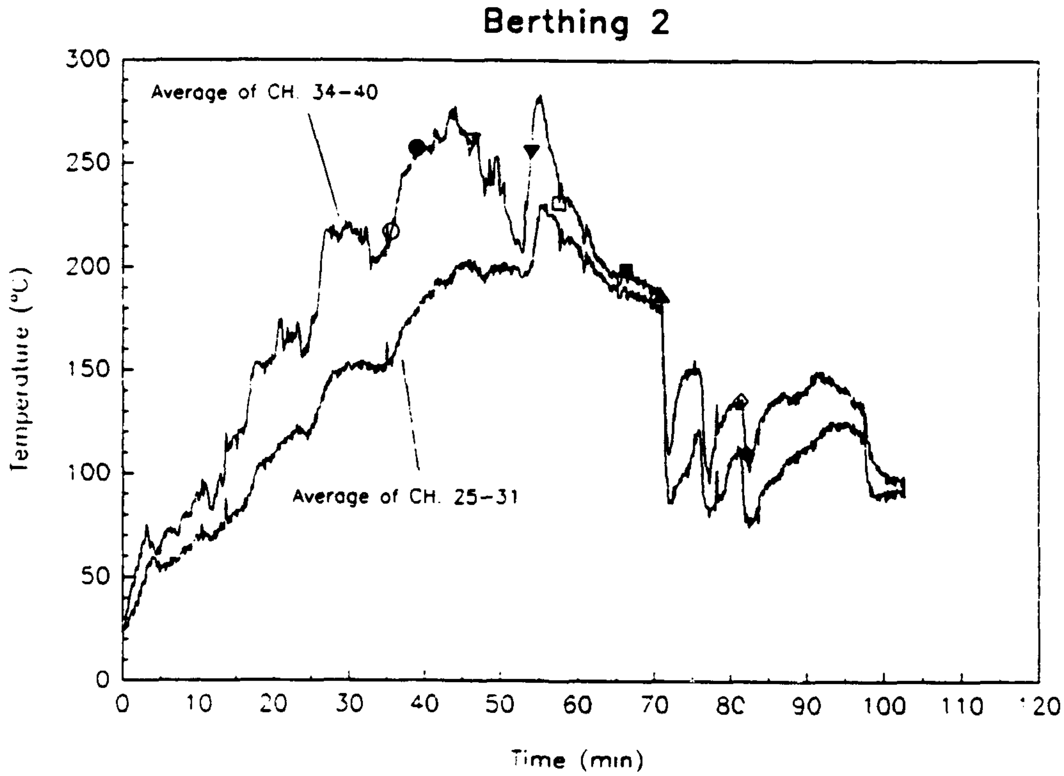
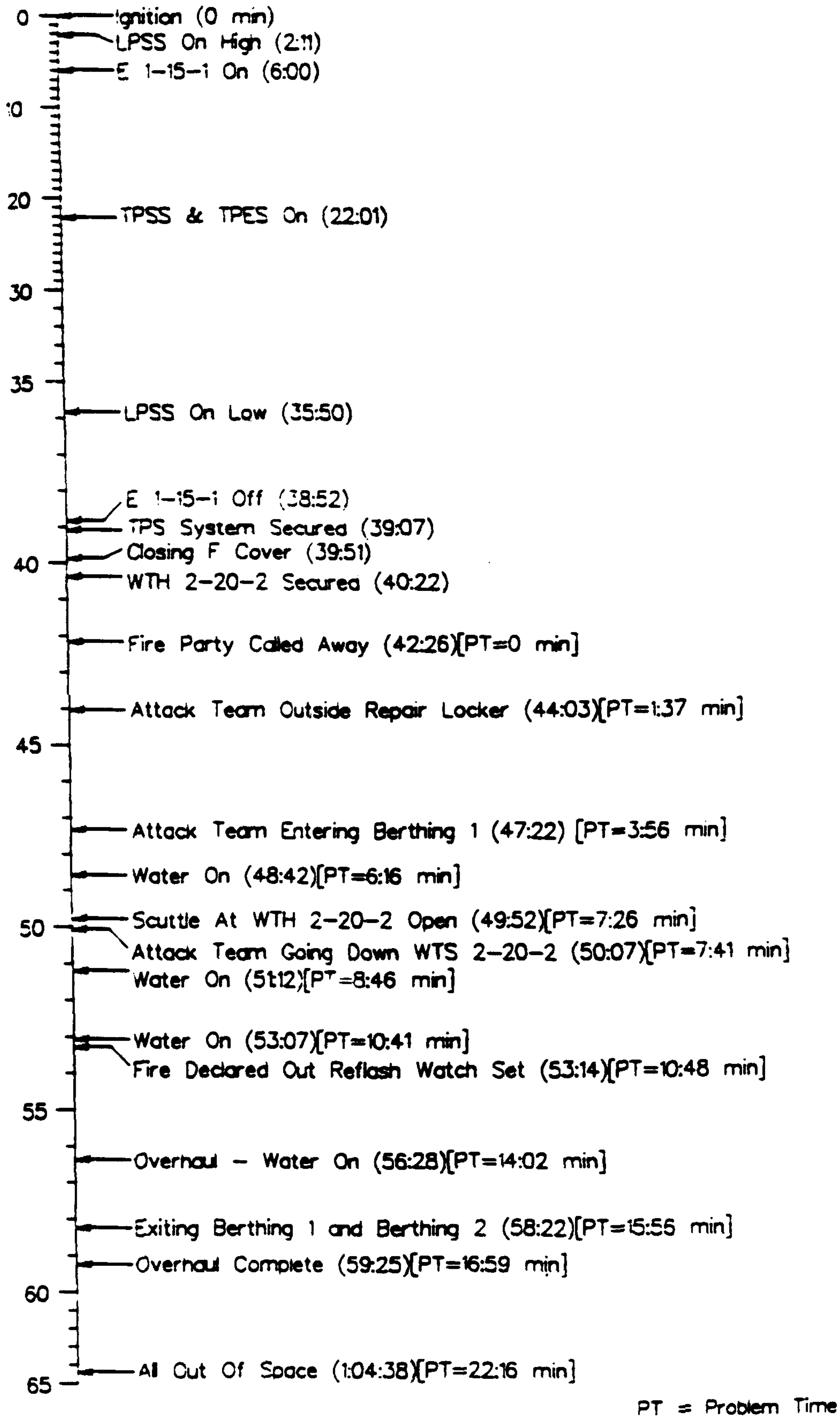
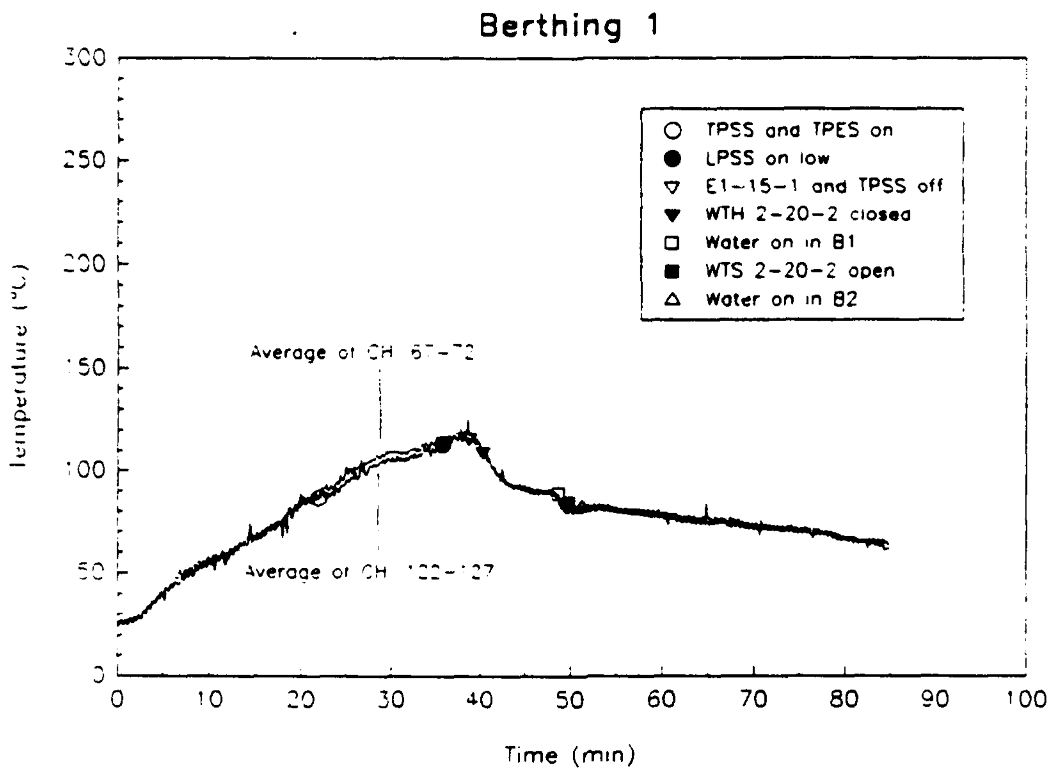


Fig. 19 – Average temperatures in Berthing 1 and 2, fd_f7

fd_f8. This first test with the Fleet participants was a comparison test with fd_f1. A single wood crib was used. Firefighters accessed the space via the scuttle installed in WTH 2-20-2. Water was sprayed on the second deck area to cool the scuttle/hatch area (in accordance with typical training procedures). Fifteen seconds of narrow angle fog with the vari-nozzle was used with a total of 83 ℓ (22 gal) used. The initial direct attack used 261 ℓ (69 gal) of water. Hosemen remained in the space and made a second attack where another 201 ℓ (53 gal) of water were used. At this point, they exited the space. At the end of the evolution, 0.31 cm (0.125 in.) of water was observed on the deck. Communications were not very good from the team leader to the scene leader. The accessman had to leave the second deck area because of heat through his boots. Personnel wearing the cool vest noted improved stay-time compared to those personnel without the cool vest. There were no desmoking actions performed during this test. Table 14 shows the sequence of events for this test. Figure 20 shows the average temperatures in Berthing 1 and 2.

Table 14. – Timeline of Events for fd_18





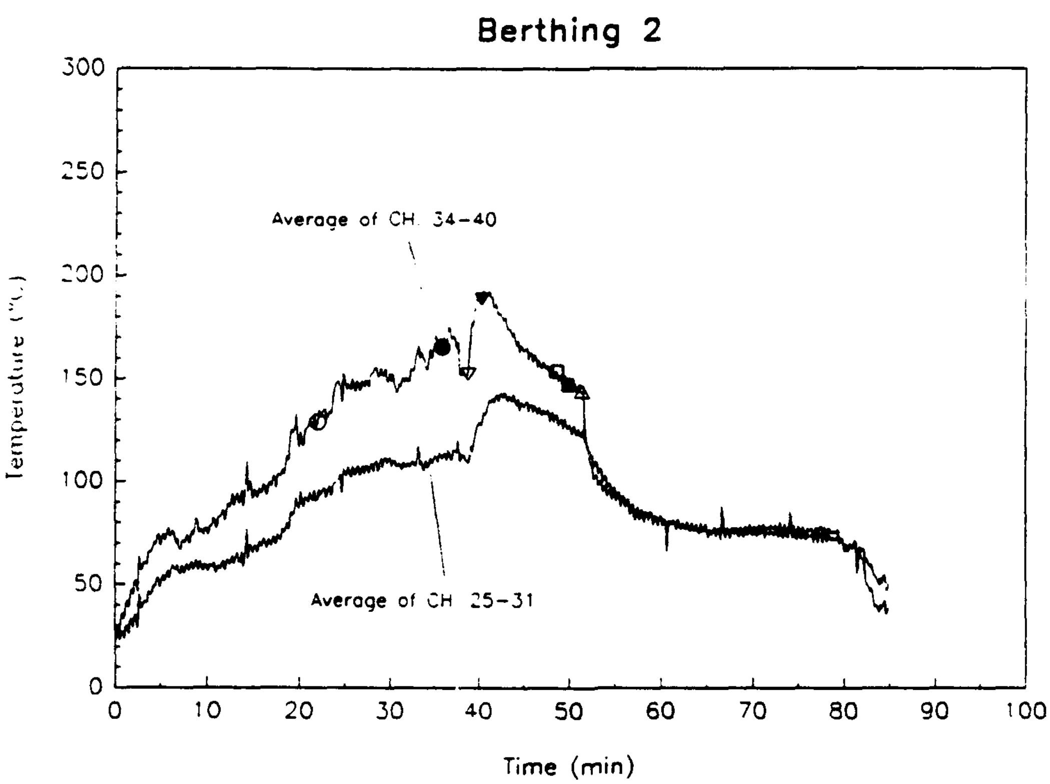


Fig. 20 — Average temperatures in Berthing 1 and 2, fd_f8

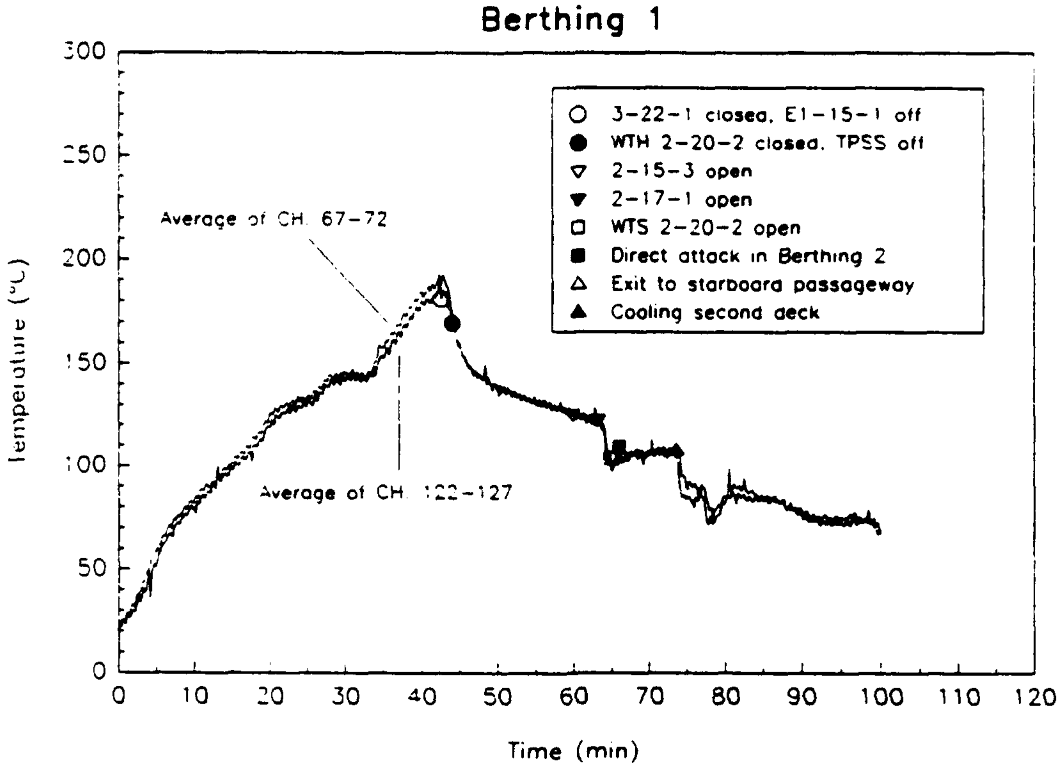
fd_f9. This test was with Fleet participants and a two wood crib threat. Again, a indirect attack was used. Desmoking was added to the scenario. The direct attack was made via the scuttle installed in the watertight hatch. A backup hose team was used as the access team, to "save" the first hose team for the attack. The direct attack was made with 140 ℓ (37 gal) of water used for hatch cooling before the team entered the space. The attack team used 151 ℓ (40 gal) of water in the initial direct attack on the third deck. Firefighters were steamed out and had to exit the space. The second team again cooled the second deck and made an indirect attack with the vari-nozzle, where 443 ℓ (117 gal) were used. A second indirect attack using two bursts of water was used to cool the burning space from the scuttle on the second deck. At that point, the fire party team had been depleted because of heat stress, and a direct attack could not be mounted.

Desmoking started before the access team entered the space. WTS 1-19-2 was opened. Before cooling was applied to WTH 2-20-2, a smoke curtain was rigged at QAWTD 2-15-3 in the starboard passageway. After the first initial deck cooling, the starboard passageway was filled with smoke and steam resulting in visibility of approximately 15 cm (6 in.). A box fan was rigged at WTD 2-22-1 in the starboard passageway that quickly cleared the passageway. About the time water was again being sprayed on the second deck from the starboard passageway, a RAMFAN was rigged at WTS 1-19-2 that improved the conditions in Berthing 1. A box fan was added at WTS 1-19-2 after the second indirect attack. The RAMFAN was placed above the box fan. Table 15 shows the sequence of events for this test. Figure 21 shows the average temperatures in Berthing 1 and 2.

Table 15. - Timeline of Events for fd_f9

- Ignition (0 min)
- LPSS On High (1:43)
- E 1-15-1 On (5:42)
- LPSS On Low (10:21)
- Methanol In Pan 2 Out (36:26)
- WTD 3-22-1 Secured (42:26)
- E 1-15-1 Secured (42:40)
- F Cover Closed (43:53)
- WTH 2-20-2 Closed (44:06)
- TPS System Secured (44:24)
- Fire Party Called Away (47:26)[PT=0 min]
- Fire Party In Starboard Passageway Opening WTD 2-15-3 (59:51)[PT=12:25 min]
- Entering Berthing 1 Through WTD 2-17-1 (63:06)[PT=15:40 min]
- Fire Party At WTH 2-20-2 (63:46)[PT=16:20 min]
- Cooling WTH 2-20-2 (64:01)[PT=16:35 min]
- Opening Scuttle At WTH 2-20-2 (64:39)[PT=17:13 min]
- Direct Attack In Berthing 2 (65:55)[PT=18:29 min]
- Exiting Berthing 2 to Berthing 1 (66:20)[PT=18:54]
- Fire Party In Starboard Passageway Ready for Indirect Attack (72:51)[PT=25:25 min]
- Water On - Spraying Second Deck From Starboard Passageway (73:33)[PT=26:07 min]
- Setting Up RAMFAN - Desmoking Starboard Passageway (75:45)[PT=28:19 min]
- Water On - Spraying Second Deck (77:10)[PT=29:44 min]
- Water On - Indirect Attack From Scuttle At WTH 2-20-2 (87:31)[PT=40:05 min]
- Water Off (88:24)[PT=40:58 min]
- Water On (88:57)[PT=41:31 min]
- Opening WTS 2-21-1 (90:21)[PT=42:55 min]
- Water Off (91:22)[PT=43:56 min]
- Water On (91:53)[PT=44:27 min]
- Water Off (92:26)[PT=45:00 min]
- Water On (92:53)[PT=45:27 min]
- Water Off (93:32)[PT=46:06 min]
- Securing Evolution - Crib #1 Still Involved (94:59)[PT=47:33 min]

PT = Problem Time



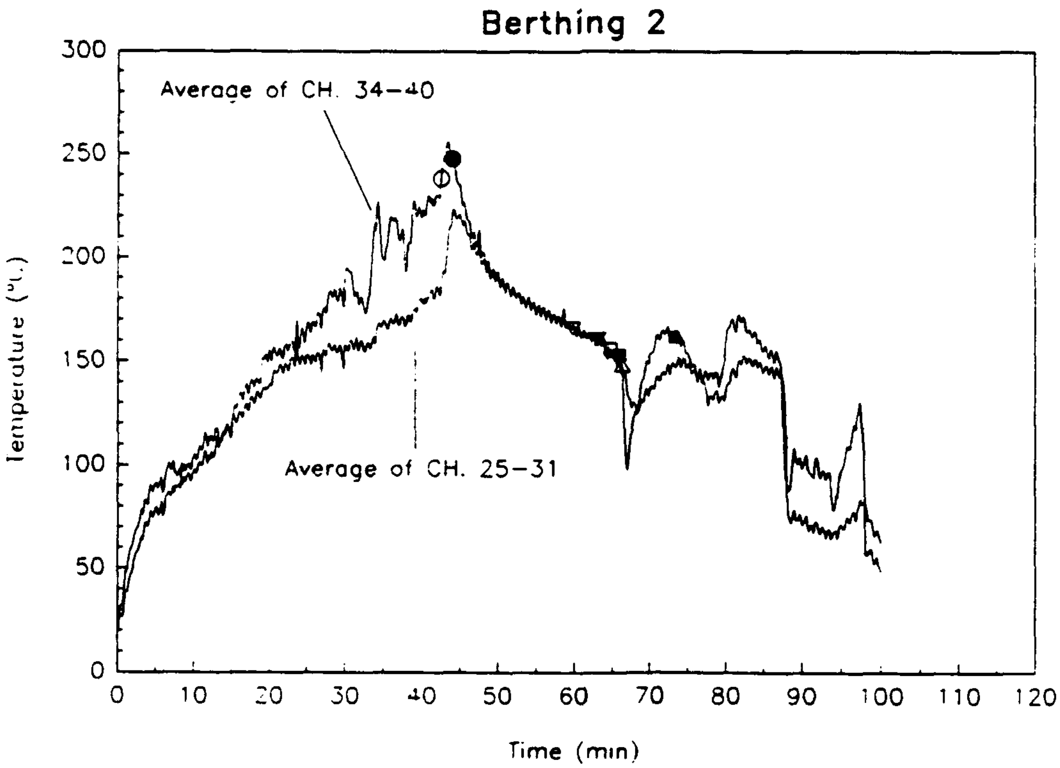
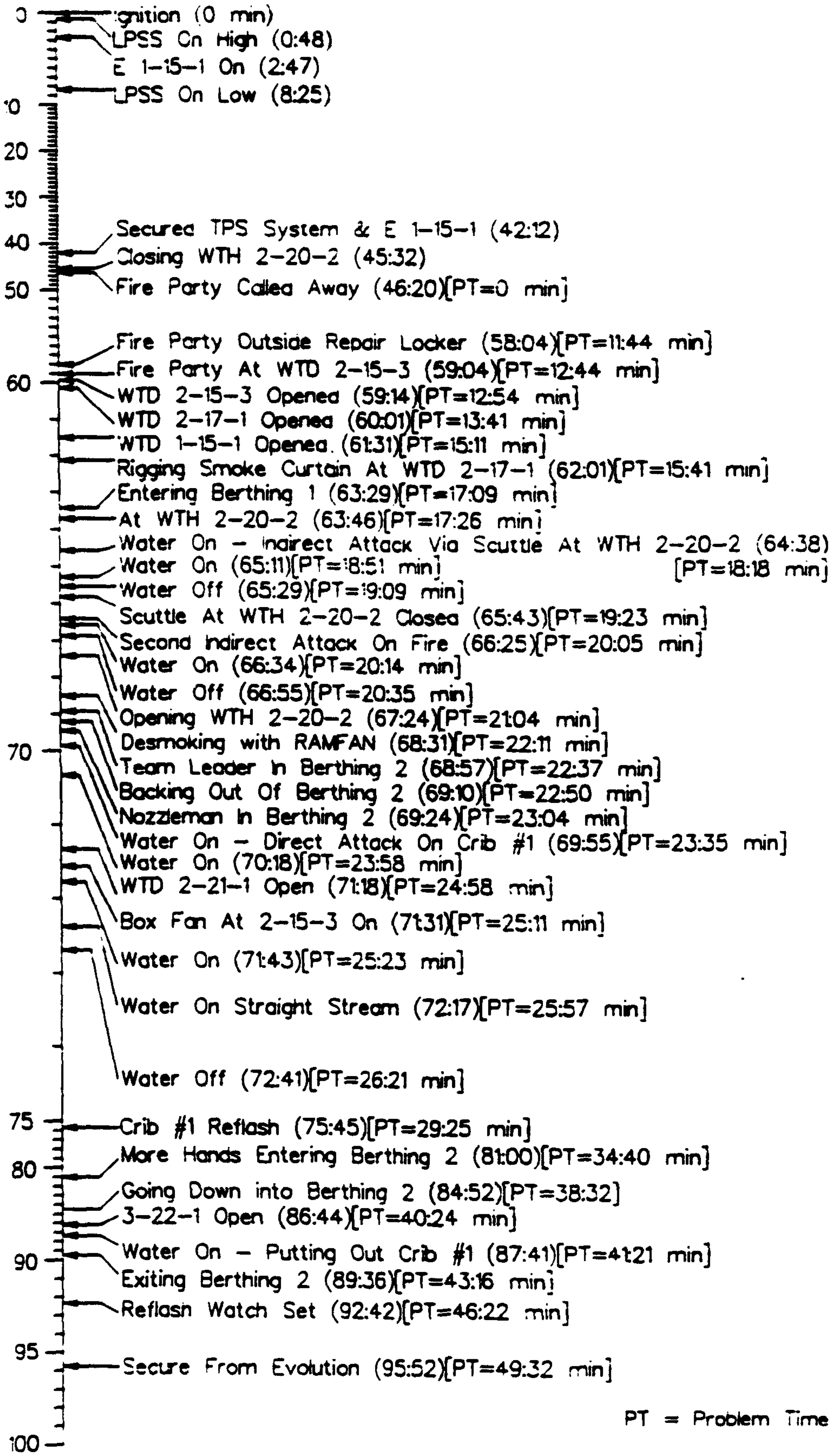


Fig. 21 – Average temperatures in Berthing 1 and 2, fd_f9

fd_f10. This was intended to be an indirect attack on a two-crib fire. After the indirect attack, the space was to be vented and then a direct attack mounted. Berthing 1 was actually vented via WTS 1-19-2 before firefighting and negative ventilation was sent up from Berthing 1. Two indirect attacks were made using 302 ℓ (80 gal) of water total. The direct attack was then mounted where 303 ℓ (85 gal) were used. The team was forced out after the direct attack.

Desmoking started after the second indirect attack. First, a box fan was rigged at QAWTD 2-15-3, then WTS 1-19-2 was opened. A box fan and a RAMFAN were rigged at WTS 1-19-2 and activated. After the direct attack, the desmoking team checked that all of the doors on the second and main decks were open. A box fan was rigged at WTD 1-15-1 to discharge to the foc'sle. A second box fan was setup at 2-11-2. Initially, supply air was not provided to the box fans; however, when the doors behind the fans were opened, a good flow of smoke was noticed. Table 16 shows the sequence of events for this test. Figure 22 shows the average temperatures in Berthing 1 and 2.

Table 16. – Timeline of Events for [illegible]



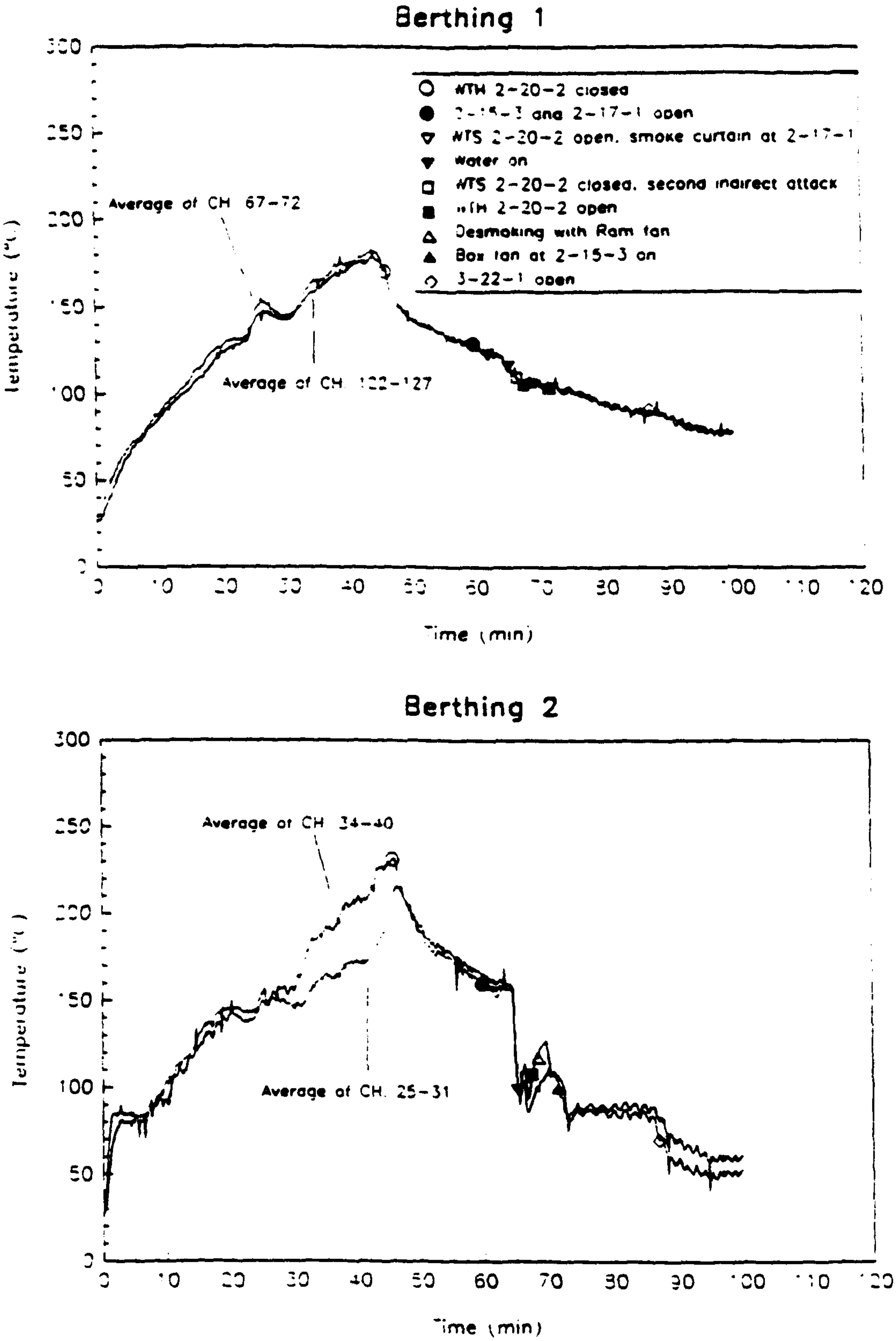
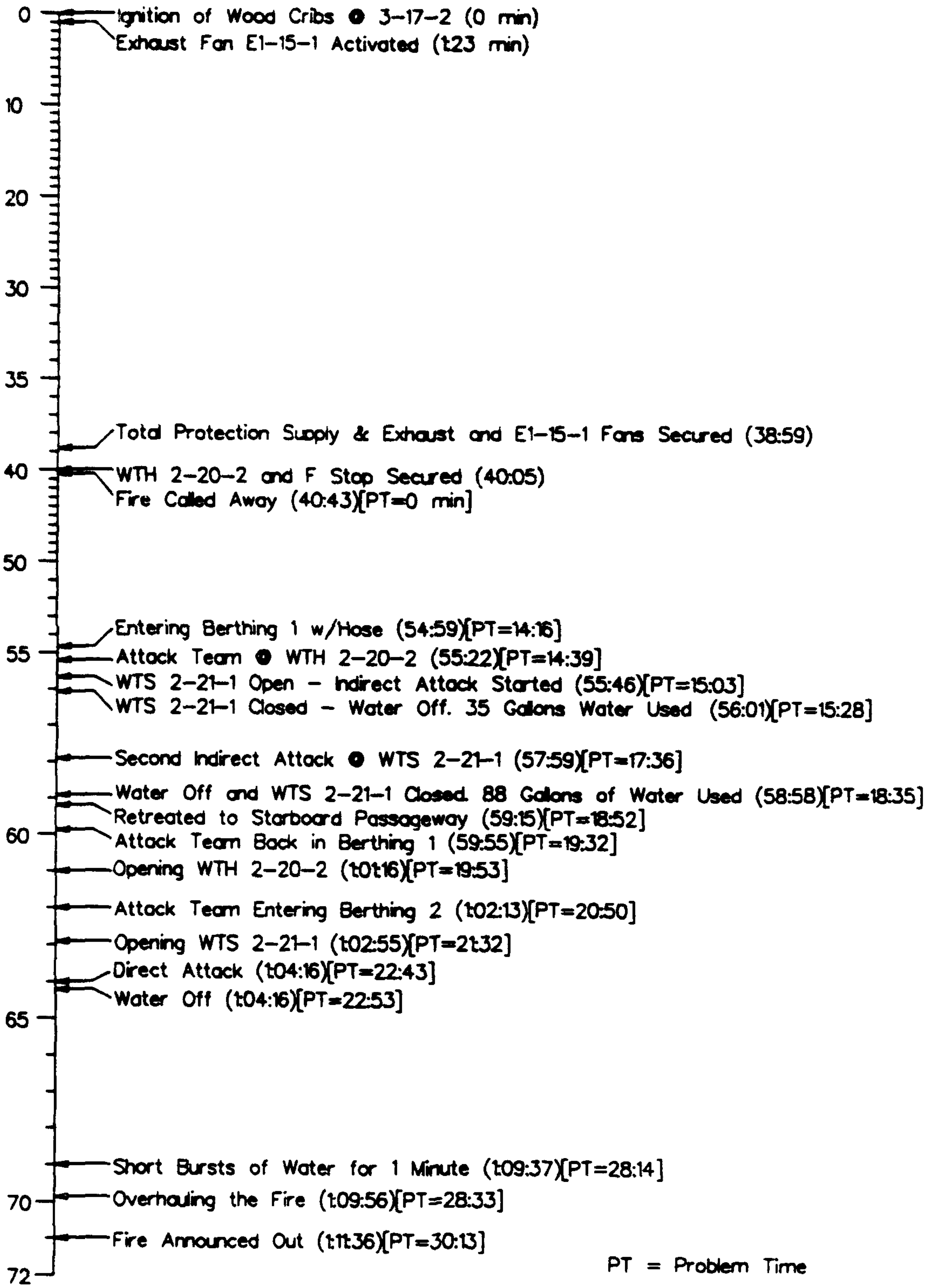


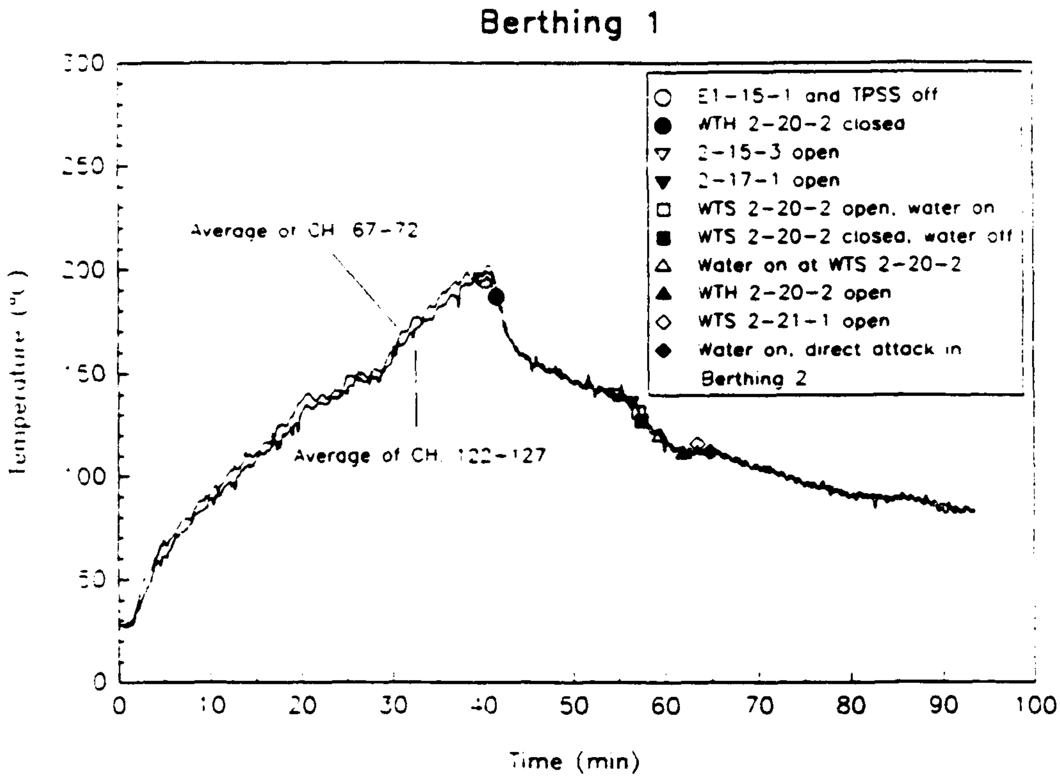
Fig. 22 – Average temperatures in Berthing 1 and 2, fd_f10

fd_f11. This was a repeat of fd_f10. Two indirect attacks were made on a two wood crib fire from WTS 2-21-1. The initial indirect attack lasted 25 seconds and used 132 ℓ (35 gal) of water. The second indirect attack lasted one minute and used 333 ℓ (88 gal) of water. Personnel then accessed the space via the watertight hatch and used short water bursts from the vari-nozzle to extinguish the fire. Firefighters used 401 ℓ (106 gal) of water in the direct attack. Another 72 ℓ (19 gal) were used in overhauling the fire. This evolution lasted through gas freeing of the space.

Desmoking started before the first indirect attack. WTS 1-19-2 was opened to provide ventilation to Berthing 1. After the first indirect attack, a smoke curtain was rigged at QAWTD 2-17-1 leading to Berthing 1 and a box fan rigged at 2-11-2. After the second indirect attack, WTS 2-21-1 was opened. After the first direct attack, positive ventilation was established in the starboard passageway by placing a box fan at WTD 2-22-1. Table 17 shows the sequence of events for this test. Figure 23 shows the average temperatures in Berthing 1 and 2.

Table 17. – Timeline of Events for fd_f11





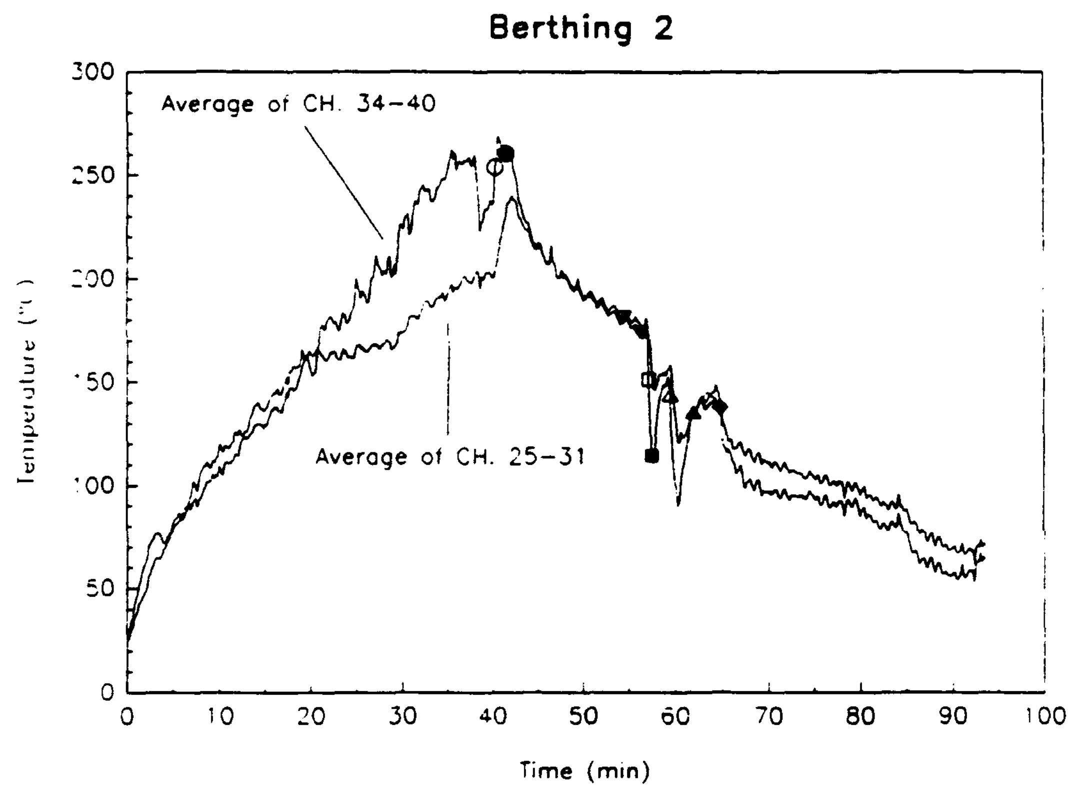
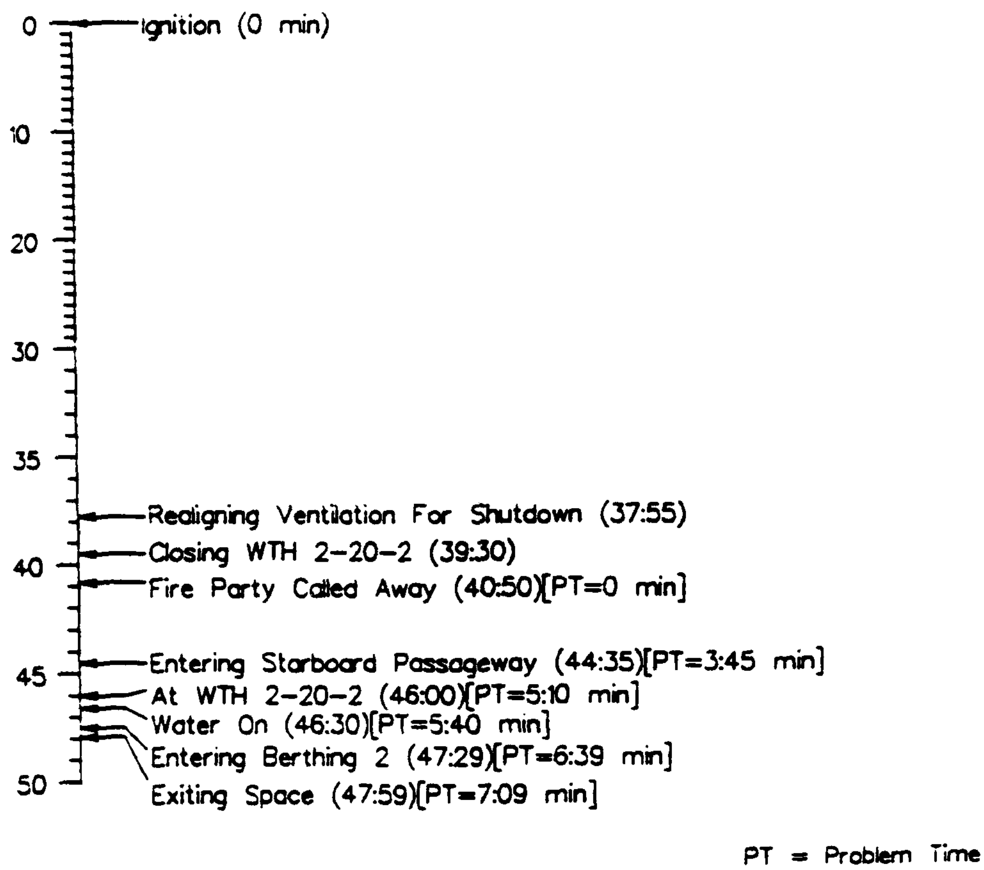


Fig. 23 – Average temperatures in Berthing 1 and 2, fd_f11

fd_f12. In this test, firefighters used the British Water Wall nozzles in general accordance with standard UK procedures as described in Reference [12]. Firefighters felt that this provided good protection while going down the ladder. There was not a great steam rush as the firefighters descended on the ladder. Those personnel burned their hands on the stanchions and ladder handrails. Personnel who did not wear rubber boots had their high-top shoes flooded with hot water. Ultimately, this resulted in steam burns. Hoses and nozzles were a little hard to handle, but the firefighting team felt that with practice they could work with this system. There was no visibility in Berthing 2 while they were making the attack, and they could not hear one another because of the roar from the nozzles. There was also water spray into the face pieces of the OBAs. On the order of 1890 to 2650 ℓ (500 to 700 gal) of water were used on the initial attack. The F-stop cover on the ship's ventilation system was left open in Berthing 1 as a safety precaution; this may have resulted in a cooler space in Berthing 1 compared to other tests. The venturi effect of air rushing down the hatch as water was sprayed from the nozzle was very evident. No active desmoking was performed. Table 18 shows the sequence of events for this test. Figure 24 shows the average temperatures in Berthing 1 and 2.

Table 18. – Timeline of Events for fd_f12



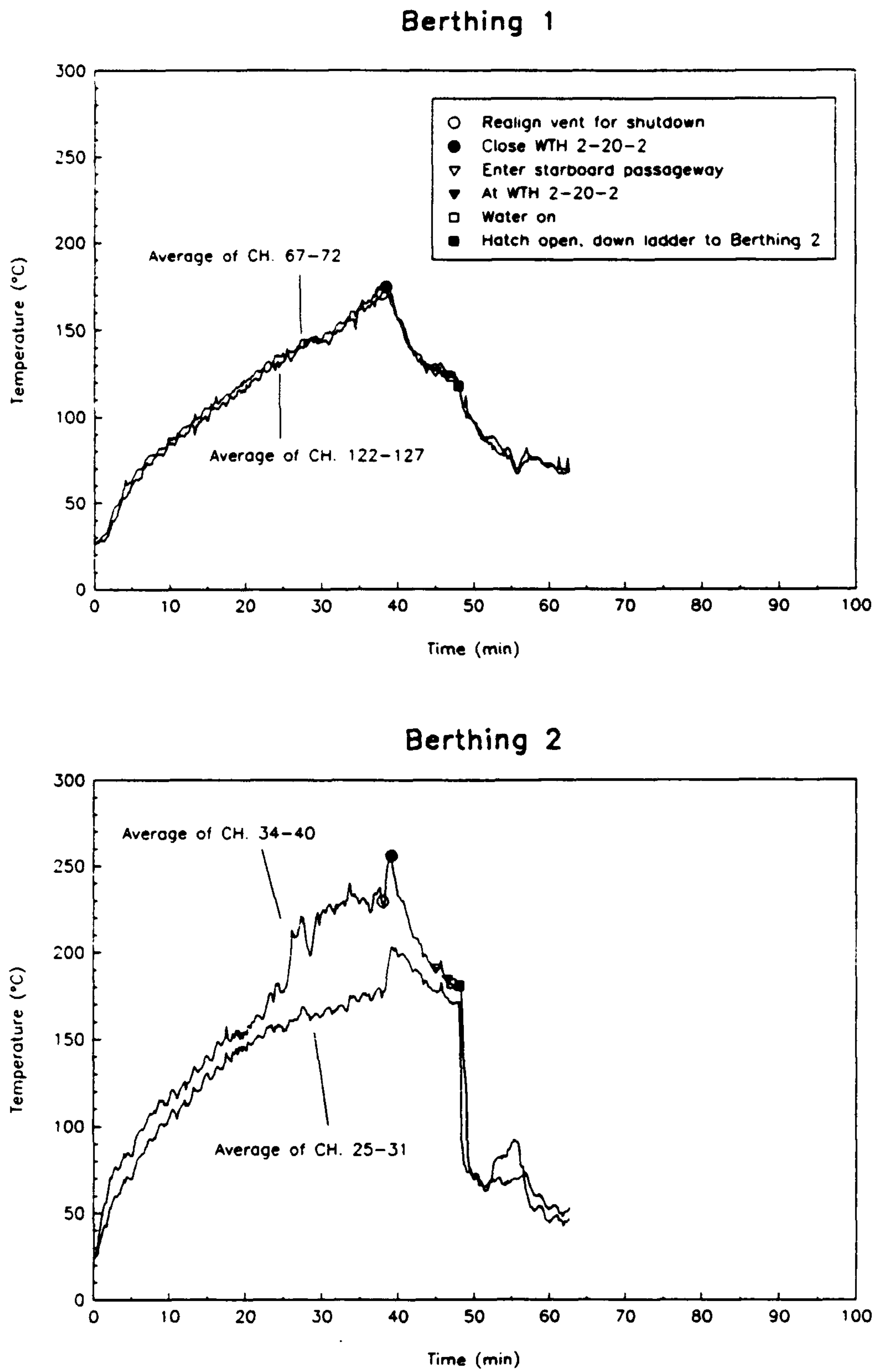


Fig. 24 — Average temperatures in Berthing 1 and 2, fd_f12

8.2 Specific Findings

The following specific findings and comments were derived from the evolutions. Where appropriate, the test reference is provided.

8.2.1 Tactics and Procedures

(1) Use an access team to assist the #1 hose team in accessing the space. This will keep the hose team fresh so that they are not worn out or fatigued before the attack (fd_f1).

(2) Use an "over-the-shoulder" technique for advancing a hose down an inclined ladder. This will prevent personnel from collapsing ("punching-out") their OBA bags (fd_f2).

(3) When 90° fog is used, gloves will most likely become wet. This may ultimately result in steam burns to the hands (fd_f2).

(4) If the hose team has a problem with equipment, backup personnel should quickly advance to help the hose team. This will reduce the effort, and the resulting fatigue will deplete the hose team. This was observed in Test fd_f3, where the hose team had to replace a bad nozzle.

(5) When using an indirect attack, the time for water application can be judged by the steam build-up. Firefighters should apply water until the pressure and steam around the access opening starts to build-up. The indirect attack should be stopped until this pressure subsides. If no pressure is observed, water application times on the order of one minute are reasonable (fd_f7, fd_f11).

(6) When using the vari-nozzle for an indirect attack, work the nozzle around the overhead using a narrow-to-wide fog pattern (fd_f11).

(7) A second person would be desirable to have with the DC personnel assigned to gas free the fire compartment (fd_f11).

8.2.2 Protective Equipment

(1) Qualitatively, the cool vests provided a significant improvement for the reduction of heat stress and an improvement in stay time (fd_f9, fd_f10).

(2) Gloves continue to be a weak link in terms of steam burns. Problems include permeability, the degree of thermal insulation, and the cuff/glove interface (fd_f3, fd_f9, fd_f10).

(3) Feet and ankles are susceptible to burns. When a vertical attack is made, large quantities of water may be used. The use of rubber boots (as opposed to high-top workboots) is required (fd_f6).

(4) Layering of protective clothing, particularly at the "weak links," is required for this threat (fd_f2, fd_f11).

(5) The NDI firefighting helmet evaluated by the SWOS safety team did not provide any protection against steam (fd_f1).

8.2.3 Communications

(1) As anxiety or fatigue/heat stress increases, the ability to communicate clearly and in a timely manner decreases (fd_f3).

(2) Feedback between WIFCOM and OBA voice amplifiers occurred in several evolutions (fd_f6, fd_f7). There was also some feedback problems with the WIFCOM base station in Repair 2 (fd_f10).

(3) WIFCOM is needed for desmoking teams to coordinate the venting tactics and setup (fd_f9).

(4) There was too much communication (or attempted communication) between the Team Leader and the Scene Leader. Standard procedure for the JESSE L. BROWN crew was to equip the Team Leader with a WIFCOM radio. Standard doctrine does not specifically prohibit this. The general consensus was that this hindered overall firefighting attack effectiveness; the Scene Leader had a tendency to focus too much on the progress of the attack team (fd_f10).

(5) Personnel need to talk slowly when using a voice amplifier (fd_f11).

(6) Hand-tap signals could be used for communication between the Team Leader and the nozzleman to improve communications (fd_f11).

8.2.4 Training

(1) Standard training does require that firefighting personnel stage in a hot environment prior to the firefighting attack, i.e., firefighters at training facilities generally stage at weather. Staging in Berthing 1 in these tests, where the indirect or direct attack was mounted, impacted considerably on the DC team effort (fd_f8).

(2) The procedure for spraying a door or hatch/scuttle with water before entry should be reconsidered. In these tests, the scuttle sprayed with water did not cool down significantly, and was still hot to the touch. The water spray did create steam, which reduced the overall tenability of the space. The

spraying of the scuttle had a net overall negative effect (fd_f9). In some cases, cooling of the deck may be needed to gain access. In that case, venting of the steam ("steam management") should be considered before applying water.

(3) Personnel should be trained to breath through their nose when using an OBA. In several evolutions, problems were created when personnel breathed hard through their mouth (fd_f10).

(4) Communication aspects in these tests were vastly different than those typically encountered in shoreside training evolutions. This was a result of integrating communications with a challenging fire scenario.

9.0 DISCUSSION

9.1 Venting and Desmoking Class A Fires

9.1.1 Venting Effects on Fire Growth

A concern with active desmoking or venting of the fire compartment is the potential for fueling the fire through the introduction of additional air. Desmoking, used in NSTM 555, is the removal of smoke from the interior of the ship, implying that the space on fire is physically isolated from the area being desmoked. Venting implies a natural relief of gases by buoyant forces, which may include the space on fire. In reality, it is difficult to separate the two phenomena. Section 6.0 described how large quantities of air are required to create the magnitude of threat observed in these tests. Greater threats, e.g., conflagrations as observed in ISCC testing [2], require even greater amounts of air. Fires of this magnitude by definition require large quantities of air. For shipboard fires, the normal HVAC system for habitability spaces (i.e., non-propulsion spaces, which have large air flows) may not alone provide sufficient air to create and sustain this threat. Air might be introduced by leakage, open doors and undampered ducts, or openings created by weapons-induced damage. In these cases, the ability to "button-up" may require considerable effort. Since, by definition, these large fires are already well vented, ventilation of the fire and adjacent spaces to aid in firefighting, using appropriate precautions, can probably be carried out with minimum additional risk. Fire boundaries should be clearly established, and the ventilation path should be carefully monitored.

A different situation occurs where the fire is difficult to access (because of heat, steam and/or smoke), but openings can be secured to a large extent. This situation was evaluated in Test fd_bb4. In earlier background burns, numerous leakage paths were identified (open stuffing tubes, poor door gasketing) and repaired. This raises the question of the state of closure on ships of the line.

Figures 25 and 26 show the Berthing 2 temperature and oxygen profiles. The temperature in the space was lower than in the fd_fx tests because a smaller crib was

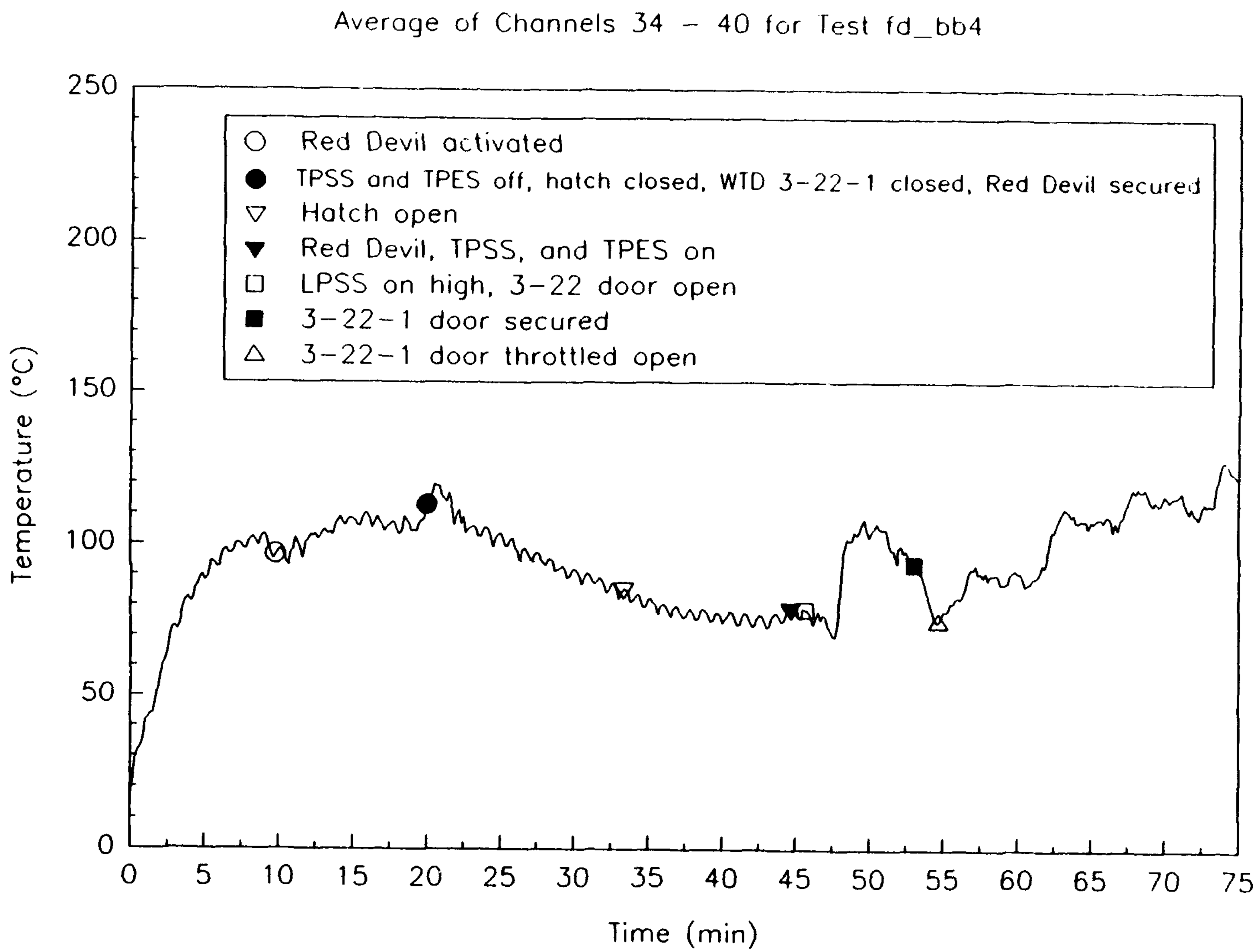


Fig. 25 – Berthing 2 average temperatures in fd_bb4

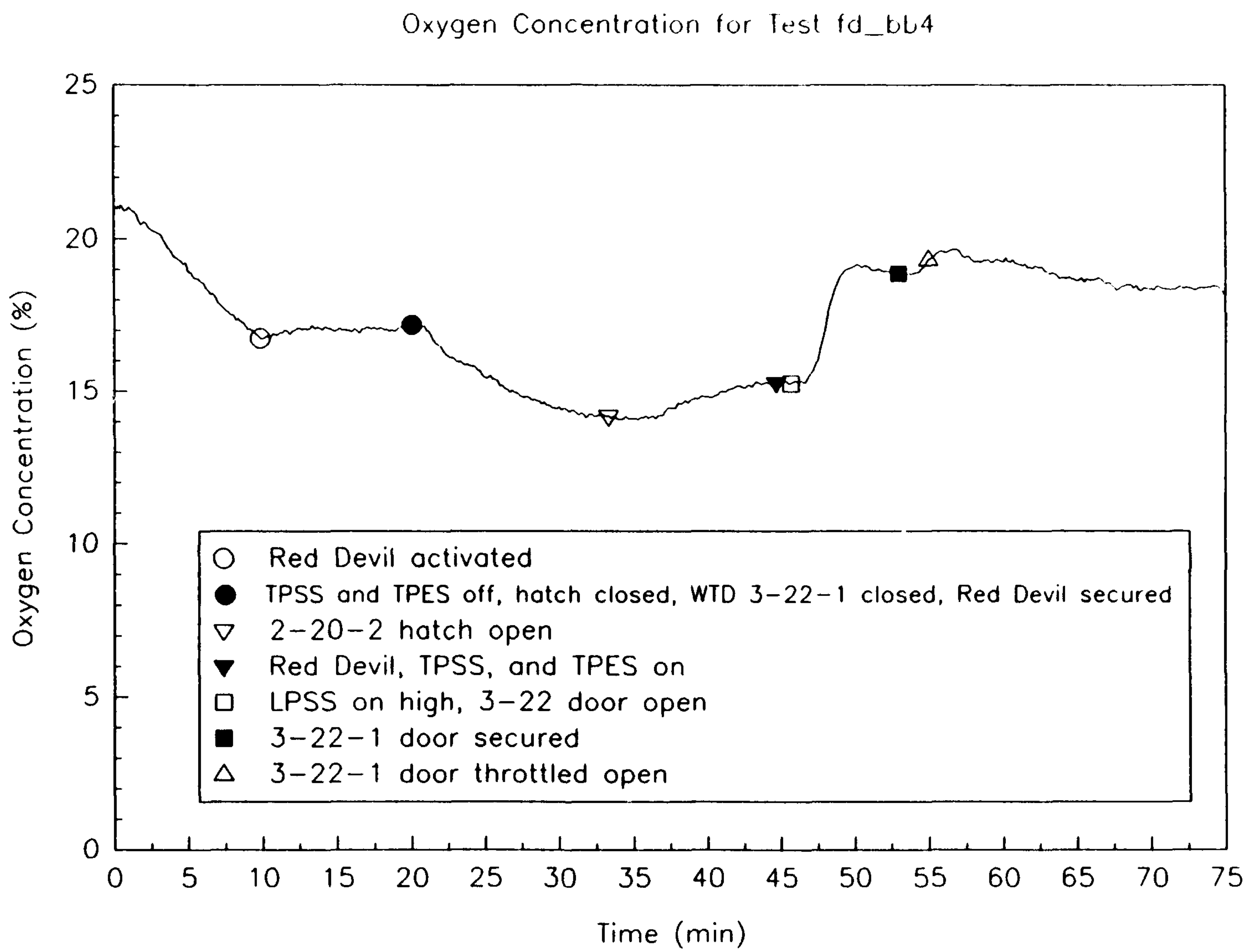


Fig. 26 – **Berthing 2 Oxygen Concentration in fd_bb4**

used. The fire was "ramped-up" using the standard procedure except that a Red Devil portable blower was also used for supply air, positioned low in the FR 22 bulkhead adjacent to WTD 3-22-1. This blower was activated and secured several times during the 20 minute ramp-up. Temperatures in the overhead were on the order of 175°C, and the oxygen concentration 2.5 m (8.3 ft) above the deck was 17%. The area was secured, with the ventilation secured and WTH 2-20-2 closed. The fire subsisted for the next 14 minutes on the oxygen remaining in the space and any air supplied from leakage through doors and the undampered supply and return ducts. The temperature followed the exponential cooling curve as described in Section 5, with the oxygen concentration dropping to 14%. The WTH 2-20-2 was then opened to determine the effects of naturally venting the fire. There was an immediate reinvigoration of the remaining methanol flame, and the oxygen concentration started to increase. There was no sustained flaming combustion observed in the crib for ten minutes, and the temperature in the compartment continued to decline. Only when the compartment was fully ventilated using the standard procedures (FR 3-22-1 door open, LPSS on) did the fire rekindle as indicated in Fig. 26.

The effects of modest ventilation of Berthing 2 after "button-up" was also demonstrated in fd_f4. In this test, the normal TPSS/TPES HVAC system (270 cfm) remained operating during the entire test. Temperature characteristics in the space follow the same characteristics (Fig. 16) as other similar tests (e.g., fd_f6, Fig. 18).

These data suggest that limited vertical ventilation in the form of open hatches or scuttles is unlikely to provide sufficient oxygen in a short amount of time to create a significant fire growth potential. The practical implication is that shipboard firefighters can utilize natural venting of a compartment, if needed, to supplement firefighting. Clearly, the attack team should be ready for the firefighting attack. The desmoking team should have appropriate ventilation paths setup.

One danger in venting the fire compartment is the effect should the fire party fail in the fire attack and have to exit and regroup. In Test fd_f9 of the series, Berthing 2 was abandoned after a direct attack with the compartment vented. The fire rekindled, although it is not clear whether the reflash was due to fresh air supplied by the venting or a door left open by a safety observer. The appropriate tactic is to button-up the space if the team has to exit.

This scenario was not tested with additional combustibles in Berthing 1 and 2 (e.g., deck tiles and mattresses). The effects of the addition of these materials will be investigated in Phase III.

Another concern with desmoking or venting to the interior of a ship is the potential for fire spread. Class A combustibles were not provided in Berthing 1. Materials will be provided in Phase III. A review of the temperature data can be used to assess the potential fire spread. Maximum deck temperatures in Berthing 1, just above the fire, were on the order of 375°C (Fig. B77). Maximum air temperatures in Berthing 1 ranged from 115-200°C (Section 8.1). The deck temperatures are well within the autoignition temperatures of cellulosic materials and within the range of some cable materials. For the hotter fires, the air temperature is approaching the autoignition temperature of cellulosic materials. The point is that there may be flaming combustion in Berthing 1 if it is fully outfitted. Firefighters will have to suppress any burning material in this area before initiating the attack on Berthing 2. The more water applied to Berthing 1, the greater the need to provide some form of smoke and heat management because of the build-up of steam (e.g., Test fd_f9). Temperatures in the Shipfitter's Shop (1-15-0-E), even with active desmoking of Berthing 1 and simultaneous venting of Berthing 2 (via WTS 2-21-1), were hot (70-75°C), but not within the autoignition temperatures of combustibles (Figs. B109 and B110). Deck temperatures were just rising above ambient (Figs. B113 and B114). The Shipfitter's Shop is a working, outfitted space with cables and limited ordinary combustibles. The only problem occurred when firefighters attempted to ventilate through WTD 1-15-1 with water fog. Water was sprayed on live electrical equipment which caused a Class C fire/casualty.

The other implication from the data from this test series is that, no matter how tight a compartment is, a Class A fire will not readily self-extinguish from oxygen depletion. Berthing 2 was not pressure tested, and there was known leakage through ducts and stuffing tubes. Similar conditions probably exist on other Navy ships, particularly older vessels. At no time during the test series did the fire totally self-extinguish during the button-up phase. Conversely, there were no situations observed where firefighters popped the hatch and the resulting in flow of air caused a dramatic flare-up of the fire (see Figs. 13-24).

9.1.2 Smoke and Heat Management

Based on the debriefings, the firefighters overwhelmingly supported the use of active venting/desmoking of the fire area, both of Berthing 1 to relieve steam/smoke for the access team/entry evolution (smoke and heat management) and Berthing 2 for relief of the firefighters. This qualitative data, combined with previous Fleet Doctrine testing using active desmoking [2,4,13], supports the implementation of this doctrine for Class A fires.

Quantitatively, the effects of venting are difficult to show from a temperature standpoint. As shown in the temperature graphs in Figures 13-24, temperatures tend to decrease exponentially independent of the ventilation technique, i.e., a dramatic temperature reduction does not occur even when mechanical blowers are used. This was previously demonstrated in the ISCC venting tests, where it was demonstrated that large natural vent areas or large capacity blowers are required to significantly impact temperature [14]. That study did point out the advantages of using natural venting for steam and smoke clearance.

These tests did provide some quantitative data on the impact of venting. Using gas concentration and smoke obscuration data as measures of smoke movement and convective cooling, the impact of venting options can be demonstrated (Figs. 27-31). This analysis technique was used in evaluating data in the Water Motor Fan tests [13].

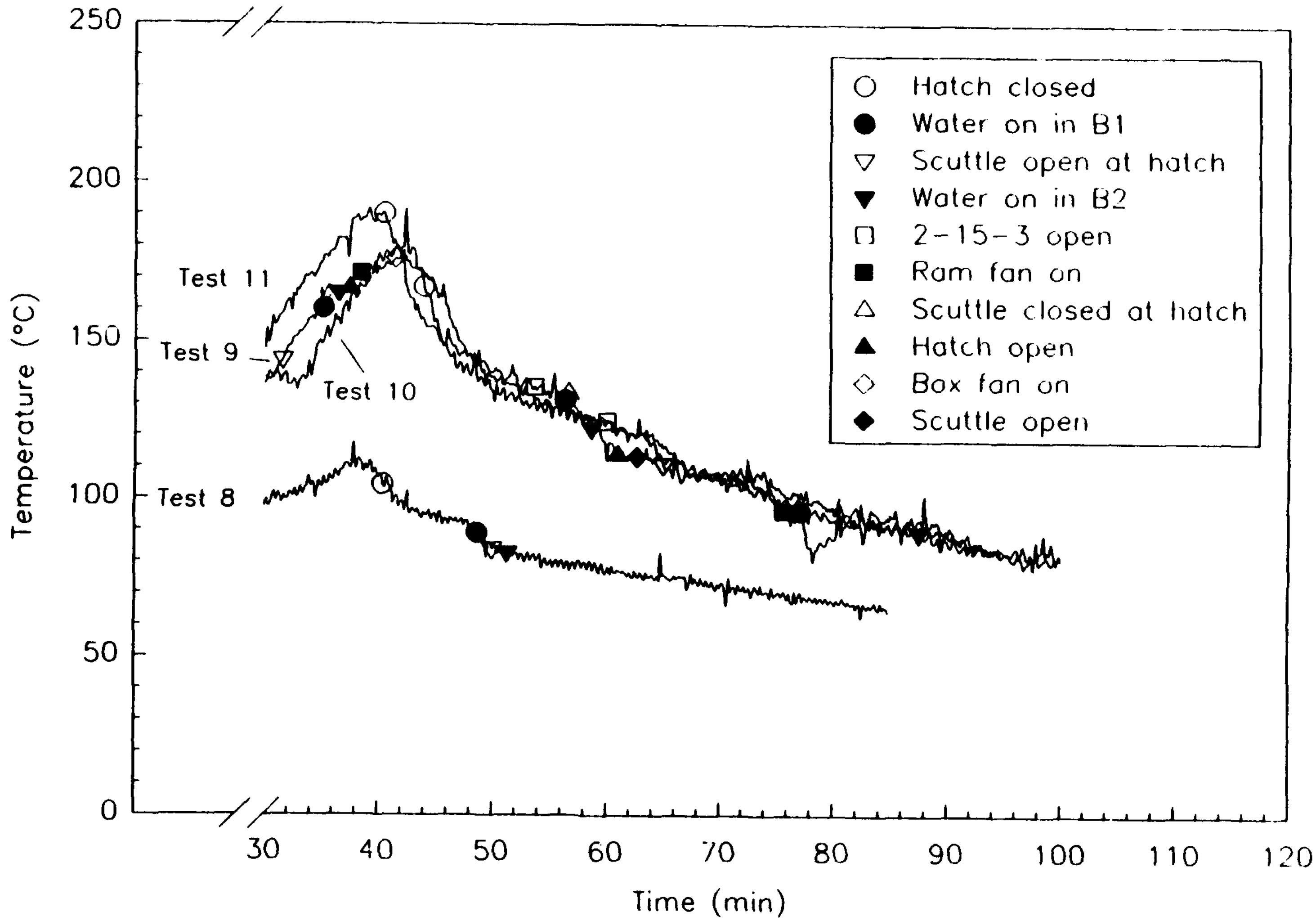


Fig. 27 – Effects of desmoking on temperature in Berthing 1

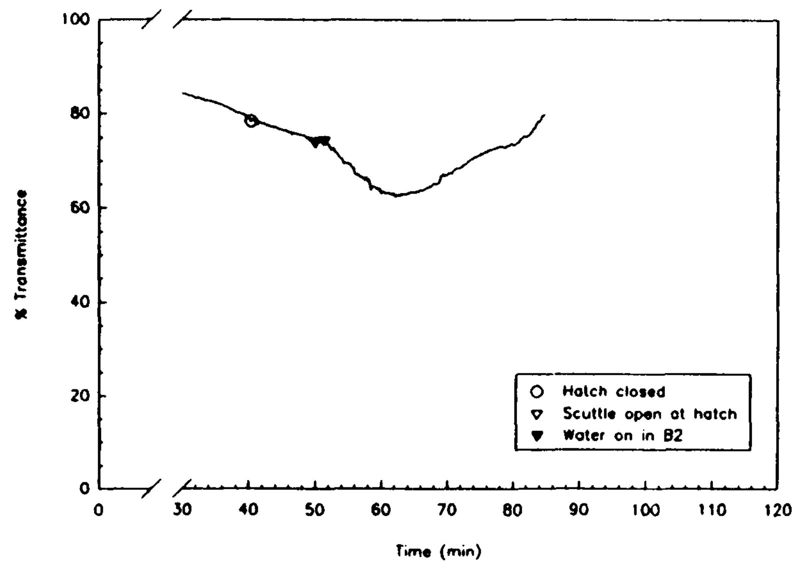


Fig 28 – Effects of desmoking on smoke density in Berthing 1, Test fd_f8

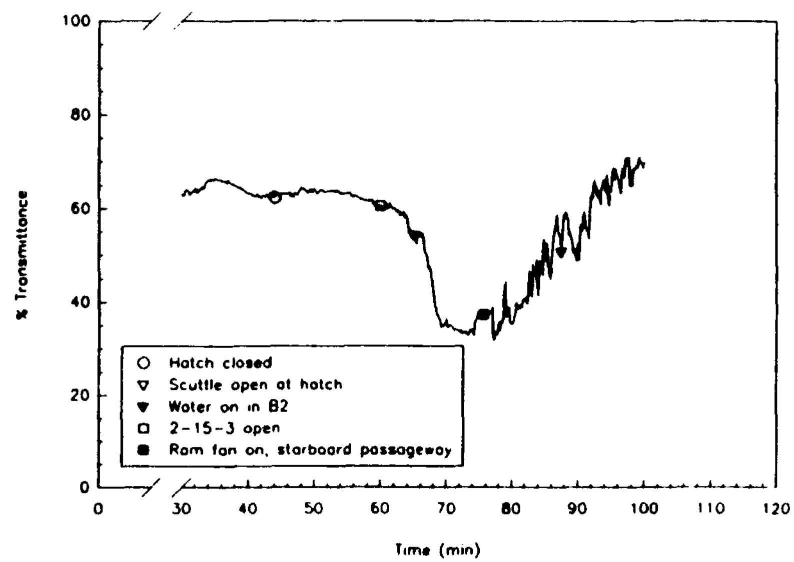


Fig 29 – Effects of desmoking on smoke density in Berthing 1, fd_f9

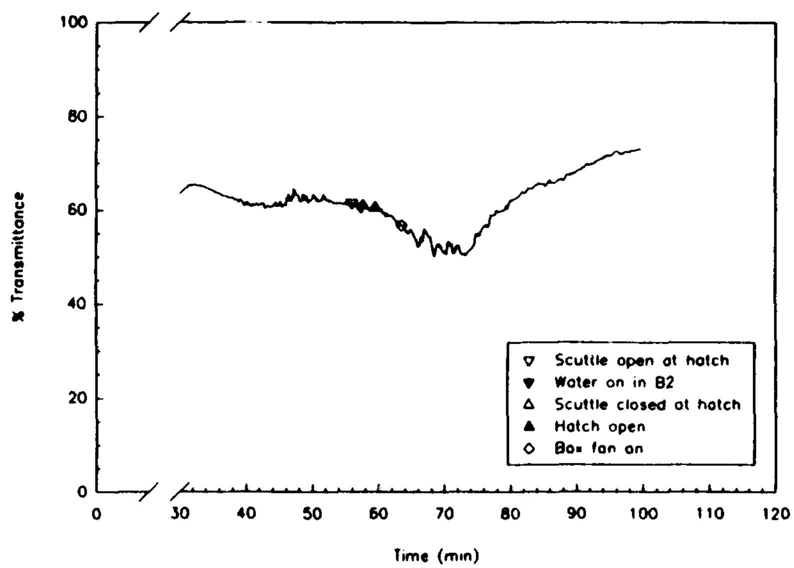


Fig 30 – Effects of desmoking on smoke density in Berthing 1, fd_f10

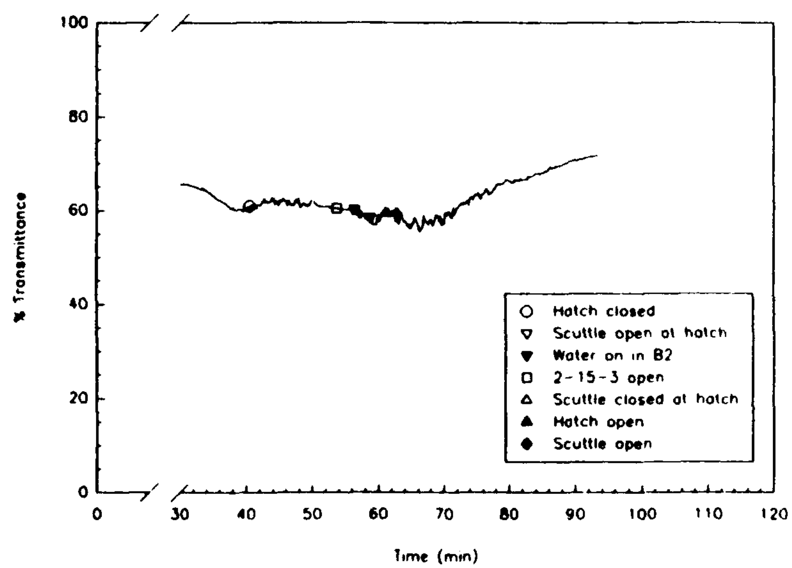


Fig 31 – Effects of desmoking on smoke density in Berthing 1, fd_f11

The effects of desmoking in the two Berthing compartments can be evaluated by analyzing the effects of specific desmoking actions on oxygen concentration and obscuration in Berthing 1. Since there was no desmoking in Test fd_f8, this test was used as a baseline and compared to Tests fd_f9 - fd_f11 in which there was desmoking. In earlier tests, the desmoking was not coordinated with the firefighting attack, and direct data correlation is difficult to pinpoint.

Figure 27 shows the effects of desmoking on Berthing 1 temperatures. As described above, there are no noticeable differences. Figures 28 through 31 show the smoke obscuration data, and Figures 32 through 35 show the oxygen concentration data. In Test fd_f8, there were no specific desmoking procedures. The oxygen in Berthing 1 dropped to about 16.5 percent. Smoke cleared naturally after the test was terminated at about 55 minutes.

In fd_f9, smoke became dramatically more dense at about 62 minutes. This is most likely a result of the firefighting team spraying water on the deck of Berthing 1, creating steam. At about this time, the RAMFAN was setup to desmoke the starboard passageway. The dramatic improvement in the smoke conditions at the 78 minute mark is most likely attributed to desmoking activities, but the time of these activities was not well documented. A RAMFAN was setup to desmoke from WTS 1-19-1. Personnel in the area noted an immediate and dramatic improvement in Berthing 1. Oxygen concentrations in the space were not dramatically affected.

After a second indirect attack in Test fd_f10 (approximately 60 minutes), desmoking was initiated in the test area as described in the test description. An improvement in the smoke and oxygen conditions is clearly evident in this time period (Figs. 30 and 34).

Smoke in Berthing 1 in Test fd_f11 was not as dense at the start of firefighting as in the other tests. WTS 1-19-2 was opened before the initial indirect attack. The reason for improvement in oxygen concentration at about the 58 minute mark could not be established.

Qualitatively, all personnel agreed that desmoking improved conditions in Berthing 1. It was more difficult to quantify these patterns since desmoking activities were carried out largely independent of the firefighting attack. Since the firefighting attack received the most emphasis, control of the desmoking effort was lost in some cases. In the August work-up series, desmoking should be more carefully controlled to provide quantitative effects of desmoking.

One key aspect of venting/desmoking is to keep the plan simple. This was demonstrated in the FDE tests where the desmoking team set ventilation paths beyond the understanding of the test team. Previous testing indicated that steam could be vented without make-up air, but that make-up air was generally needed for efficient smoke removal.

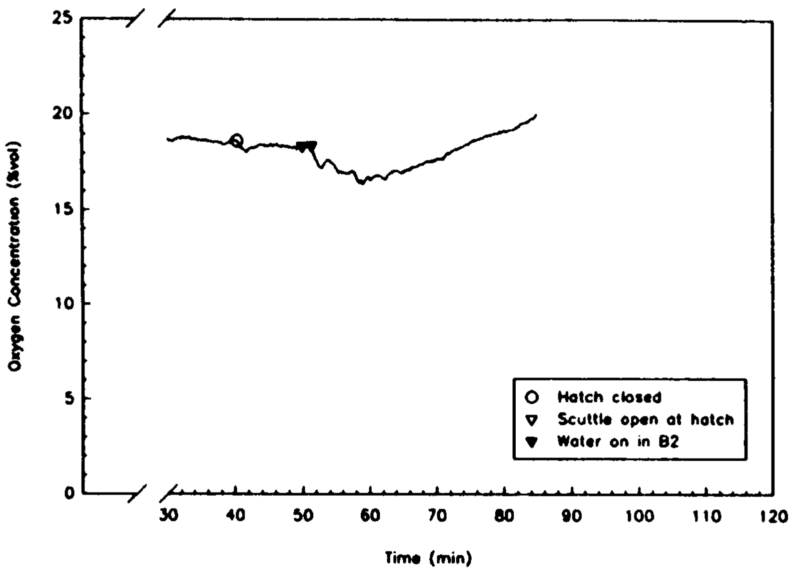


Fig. 32 – Effects of desmoking on oxygen concentration in Berthing 1, Test fd_f8

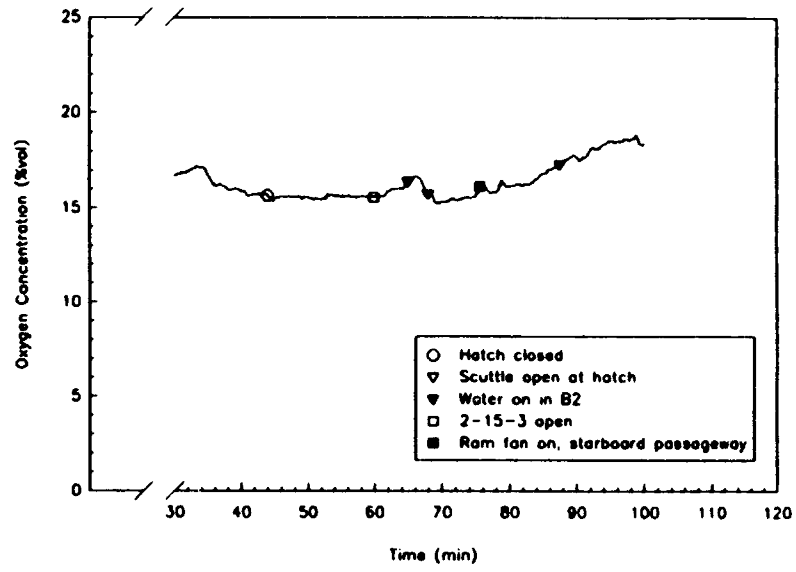


Fig. 33 – Effects of desmoking on oxygen concentration in Berthing 1, Test fd_f9

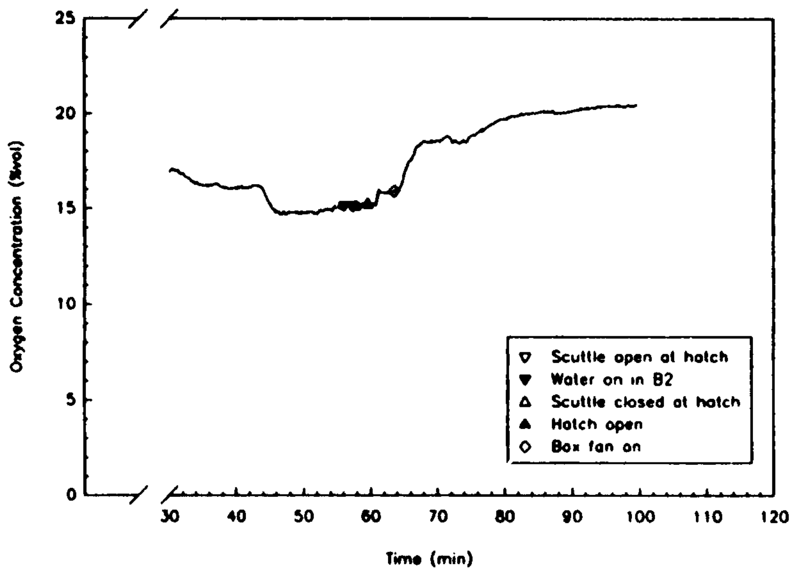


Fig. 34 – Effects of desmoking on oxygen concentration in Berthing 1, Test fd_f10

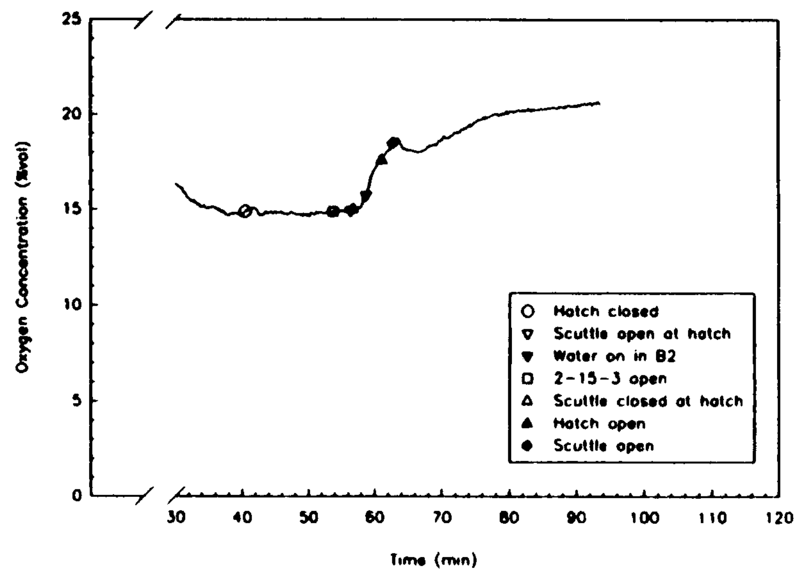


Fig. 35 – Effects of desmoking on oxygen concentration in Berthing 1, Test fd_f11

9.2 Direct and Indirect Attack Techniques

There is no single criteria for when a direct or indirect attack should be used. In these tests, with the two crib threat, the indirect attack clearly made the eventual direct attack easier. There were successful direct attacks on the two crib scenario although stay time of the nozzleman generally was short. Direct attack on the one crib fire was successful. A rule-of-thumb to use is to attempt a direct attack if the access route is sufficiently tenable; otherwise, an indirect attack can be used. In both the one and two crib situations, the overall threat was probably many times greater than that seen at fire schools. Even the SWOS safety team required several evolutions to get fully acclimated.

A range of vari-nozzle patterns were used in the direct attack. No pattern was significantly better than another in terms of firefighting efficiency and steam production. Medium and wide angle fog was used for control and extinguishment, and straight stream was used for direct attack where the fuel source was immediately obvious. Straight stream resulted in less water used, but where multiple fuel packages are involved, the fog pattern may be just as efficient. The fog pattern does provide more rapid overall cooling of a space, with the penalty of increased steam production.

The use of the Navy All Purpose Nozzle (APN) with sprinkler attachment for indirect attack (fd_f7) was compared to the vari-nozzle (fd_f6) for indirect attack. Qualitatively, the Navy All Purpose Nozzle was judged to have slightly better cooling characteristics in these tests. However, differences in the data do not strongly suggest an advantage for either nozzle. Test observers said that more steam was produced in fd_f7 with the APN compared to the previous test with the vari-nozzle. There was some feeling that this was due at least in part to a greater fire temperature in fd_f7. A comparison of Figs. 18 and 19 and Table 4 shows that this is true; fd_f7 had a hotter upper compartment temperature and a longer preburn time. The results can be compared with fd_f11 where an aggressive indirect attack was made on a high challenge fire with the vari-nozzle. After two attacks, water usage was roughly the same: 636 ℓ (168 gal) for the APN compared with 466 ℓ (123 gal) for the vari-nozzle. Figures 36 and 37 show that the cooling from the APN, as measured by the magnitude of the reduction in compartment temperature, is moderately better at least initially for the APN with sprinkler. Intuitively, this is expected since the sprinkler has a finer water pattern. The use of the APN with the sprinkler nozzle may be more efficient for indirect firefighting, but its use must be balanced against the time to set it up and its use in direct firefighting after the indirect attack.

There was no general agreement on the use of a smoke blanket for protecting an opening for indirect firefighting. Some believed that the blanket was useful to contain steam and keep the compartment "buttoned up." Others felt that the steam threat to personnel performing the indirect attack was essentially the same in either case, and that it took longer to stage the blanket.

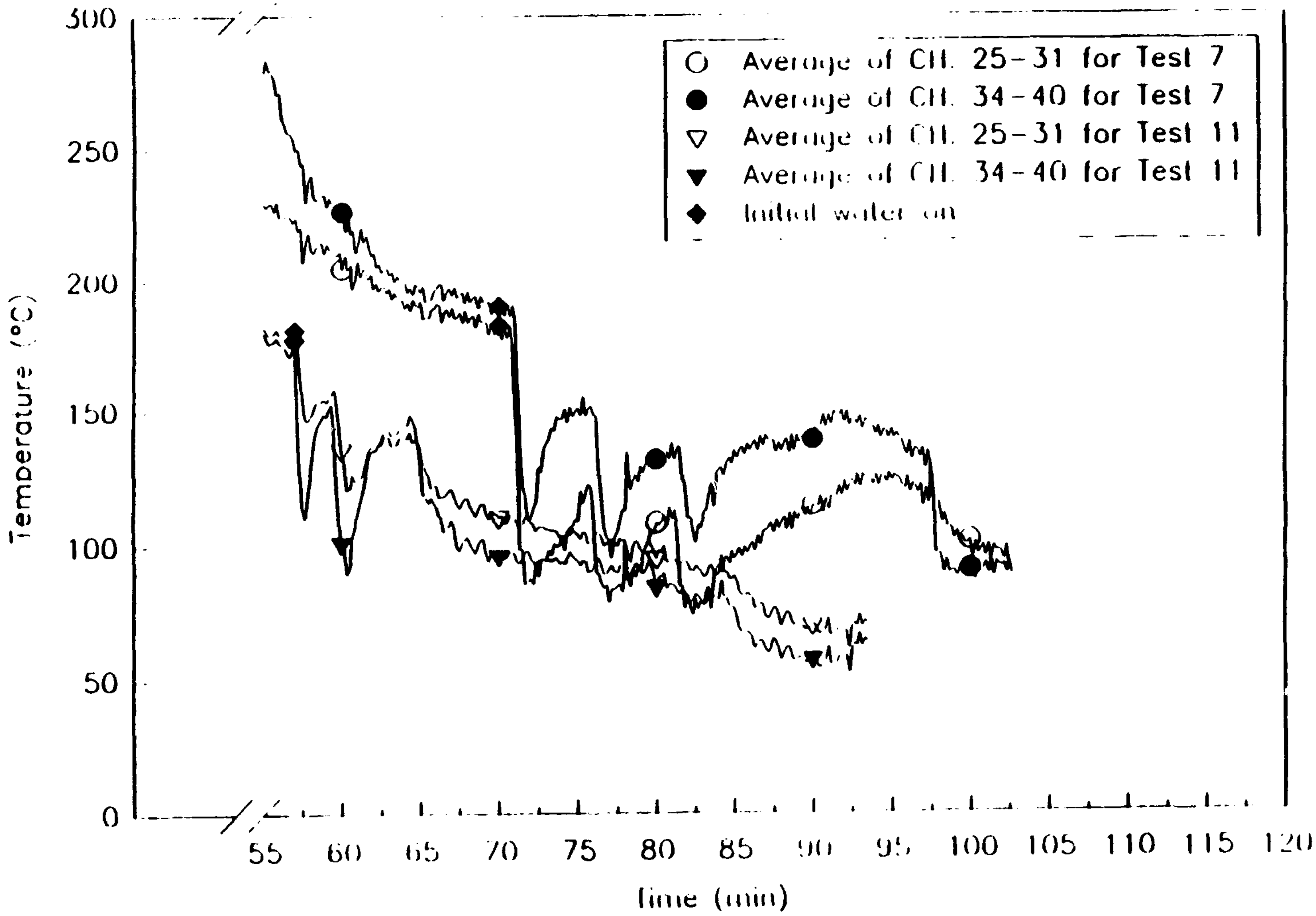


Fig. 36 – Effects of indirect firefighting techniques on Berthing 2 air temperatures

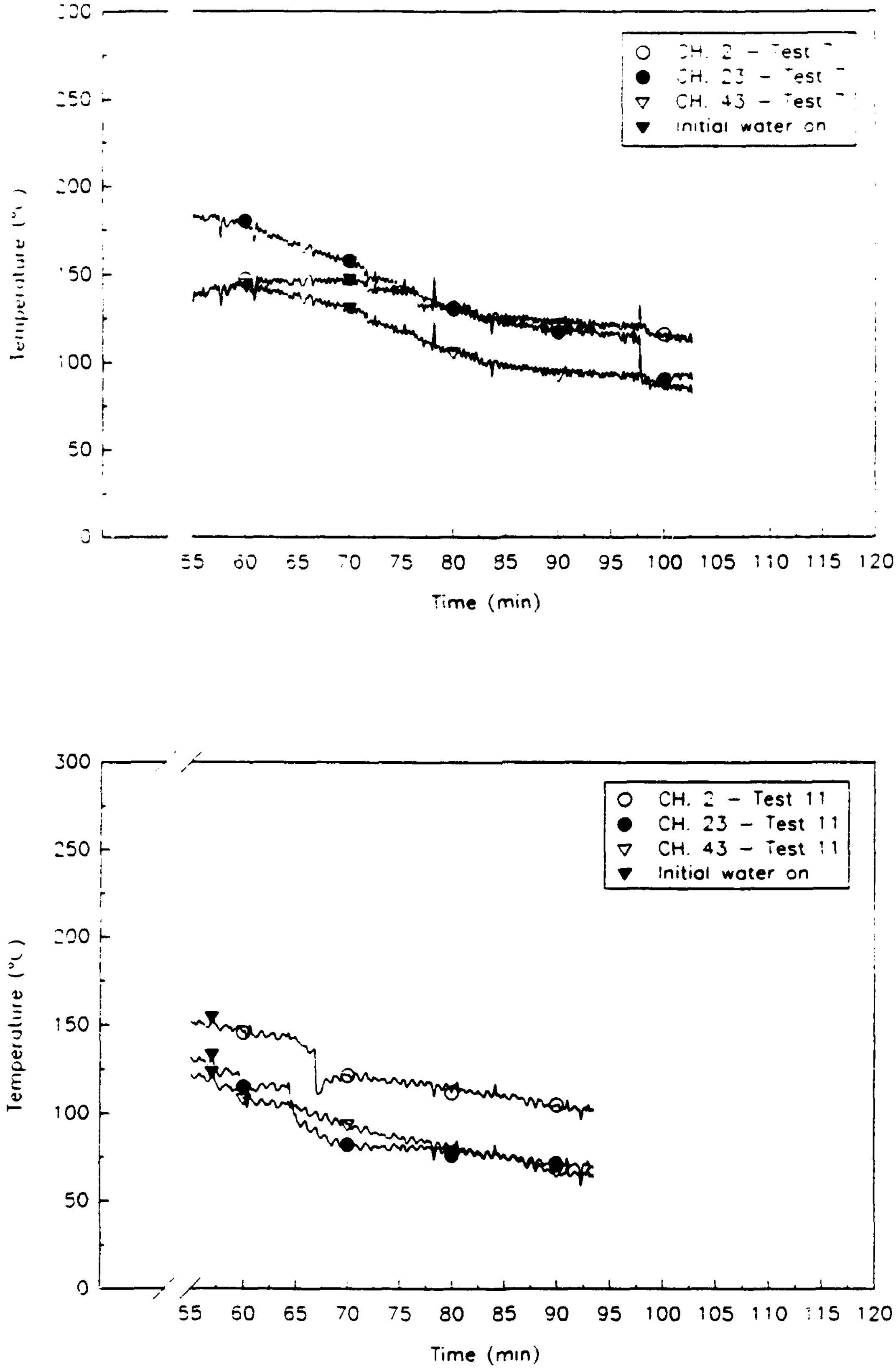


Fig. 37 – Effects of indirect firefighting techniques on Berthing 2 bulkhead temperatures

The use of a smoke blanket over the access hatch/scuttle to contain smoke and heat while there is a direct attack will probably result in steam burns to the attack team. There is no escape path for the steam. A better alternative is to leave the hatch open and have a vent path for the steam/smoke in the compartment above (see previous section).

There was no apparent advantage in cooling the scuttle/hatch before accessing the space. The scuttle remained hot to the touch, and substantial steam was created.

9.3 Water Wall Technique

The British Water Wall technique was successfully used in Test fd_f12, but at a penalty of substantial water usage (1900-2600 L, 500-700 gal) and steam burns to the firefighters. Positive aspects included limited initial steam "rush" or blast to the attack team because of the water wall protection provided. The hot water on the deck resulted in one firefighter, wearing high-top boots, to exit the space. Visibility was zero, and personnel could not communicate because of the noise from the water discharging from the nozzle. The participants noted that it was difficult to coordinate the two hoses within the confined space. There was definitely a "venturi" effect as the water was discharged down the ladder.

Participants felt that the water wall technique might be useful if the hatch cooling aspect was eliminated and the fire compartment was vented simultaneously with the attack.

9.4 Training Issues

Fleet feedback from this and all previous SHADWELL evolutions has been extremely strong. Participants, including the most senior and experienced damage control personnel, have been struck by the realism of exercise situations. Common comments have indicated that few had any expectation of the physical and mental stress they experienced during the exercises. Some of the typical comments included "The heat was more than I could bear;" "The communications were terrible;" "We just did not have enough people for everything that was going on;" "It was easier to get lost in that smoke than I thought it would be;" "The steam cut like a knife;" "Passageway congestion was too much!"

Comments from this series and the 1991 and 1992 FDE tests have been unanimous in confirming that no shipboard drill or shoreside trainer presents the level of stress which cause the simplest tasks to become overwhelming. Shoreside fire school exercise fires, which by nature are much less stressful, are not conducive to the integrated approach. For example, communications requirements are limited to the hose team only. Conversely, shipboard training exercises involve broader communications without any significant physical threat.

The need to conserve assets, in particular manpower, never becomes so apparent in training as it does during full-scale firefighting evolutions. Recognition of conservation of resources or application of damage control efficiencies are not currently used by existing curricula and facilities.

Training facilities should be capable of presenting combined sets of multiple and concurrent challenges where procedures are used in stressful situations and the resulting techniques developed by individuals are those techniques which work. While our school system is providing personnel with fundamental knowledge and skills, a clear need for an advanced damage control training curricula and facility has been demonstrated in the SHADWELL FDE tests.

10.0 CONCLUSIONS

(1) The appropriate doctrine for Class A fires should still be to initially "button-up" a space where there is a fire. However, to gain access, the access route and fire compartment can be vented to improve access and firefighting. Class A fires may continue to burn or smolder when "buttoned-up" due to air leakage through doors, undampered ducts, and open stuffing tubes. If firefighters need to exit and leave the fire compartment unmanned before the fire is extinguished, doors, hatches, and scuttles should be resecured to the maximum extent possible. This includes use of smoke curtains to deny oxygen to the fire.

(2) For the scenario and fuel load tested, modest vertical vents, e.g., scuttles and hatches to a compartment, do not appear to significantly change Class A burning characteristics during the time when firefighters are expected to make their initial access and attack. Effects of additional fuel loading will be evaluated in Phase III.

(3) Direct or indirect tactics can be successfully used in a vertical attack of a below-decks Class A fire. The judgement to use a direct or indirect attack is a function of the ability of the attack team to gain access and remain in the space. A vari-nozzle or All Purpose Nozzle can be used for the indirect attack.

(4) Smoke and heat management during firefighting below decks can improve access and firefighting. Desmoking routes, which should be preplanned by the Repair Party, should be kept as simple as possible.

(5) Natural venting/desmoking can be supplemented by mechanical equipment. It is preferable to establish the vent path from weather back to the affected space.

(6) It was again demonstrated that the ice vest provides a substantial reduction in heat stress/fatigue to sailors in the Repair Party, particularly the attack team.

(7) Protective equipment, in particular gloves, continue to be an issue in the firefighting tests.

(8) Integrated damage control scenarios, involving the entire Repair Party including the Repair Locker and DC Central, continue to evolve on the SHADWELL. The Phase I FDE test series was the most advanced to date, including communications, sensors, and gas free engineering. The inclusion of collateral damage (flooding) in the Phase III tests will advance the state of the art. As the scenarios become more advanced (and more representative of actual shipboard casualties), the limitations of current training curricula and facilities become more obvious.

11.0 RECOMMENDATIONS

(1) Subject to the verification tests to be conducted with an entire Repair Party in Phase III, draft doctrine and tactics for active desmoking of Class A fires are scheduled for incorporation in NSTM 555 and NWP 62-1. Tactics and procedures for attacking a below-decks Class A fire should be revised based on the data from these tests.

(2) Provide the ice vests to the Fleet.

(3) Representatives from the protective clothing, communications, and training communities should be active participants in the Fleet Doctrine Evaluation tests on the SHADWELL.

(4) Initiate a project to develop an advanced damage control/firefighting curricula and facility based on the lessons learned on the SHADWELL.

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APPENDIX A
Instrumentation Layout

Instrumentation Notes for fd_f1 - fd_f12

1. Gas sampling systems – CH 183, 185, and 189 out of service for these tests.

2. Calorimeter CH 50 (3rd deck) was in service starting with fd_f4; calorimeter CH 51 (at hatch) was in service starting with fd_f10. Channels 175 and 176 on the second deck did not respond with reliable data.

3. Starting with fd_f4, CH 9 TC was in Crib #2.

4. Ultrasonic flowmeters were recalibrated after fd_f4; prior readings may be approximately 10% low.

5. Starting with fd_f5, TC CH 136 and 137 were removed from the Shipfitter's Shop deck and installed as air thermocouples as shown on the drawings.

6. Starting with fd_f6, the microswitches at WTH 2-20-2 (CH 169) was out of service. By the conclusion of the tests, CH 115 (QAWTD 2-17-1) and WTS 2-21-1 (CH 120) were also out of service.

7. ODMs were rezeroed after fd_f7.

8. Water flowmeter data from CH 171 may be in error starting with fd_f10.

9. Logic switches – Logics 4-6 not responding accurately.

10. Air pressure conventions
    a. QAWTD 2-17-1 (CH 118) – positive on Berthing 1 side.
    b. QAWTH 2-20-2 (CH 54) – positive on Berthing 1 side.
    c. WTS 2-21-1 (CH 55) – positive on Berthing 2 side.
    d. QAWTd 2-15-3 (CH 53) – positive on forward side.

KEY

T_O	Thermocouple overhead — one pair 6'' and 18'' below the overhead
T_A	Thermocouple air
T_B	Bulkhead thermocouple — one on each side of bulkhead 60 in. above the deck except as noted
T_D	Deckmount thermocouple — one thermocouple located on the deck on the side indicated by the drawing
T	Thermocouple tree
T_C	Thermocouple crib
T_L	Thermocouple lintel
OD	Optical density meter
S	Door micro switch
G	Gas line
C →	Camera
A	Audio
L	Load cell
IR →	NFTI
U	Ultrasonic flow meter
R	Radiometer
C	Calorimeter
P_Δ	Differential pressure

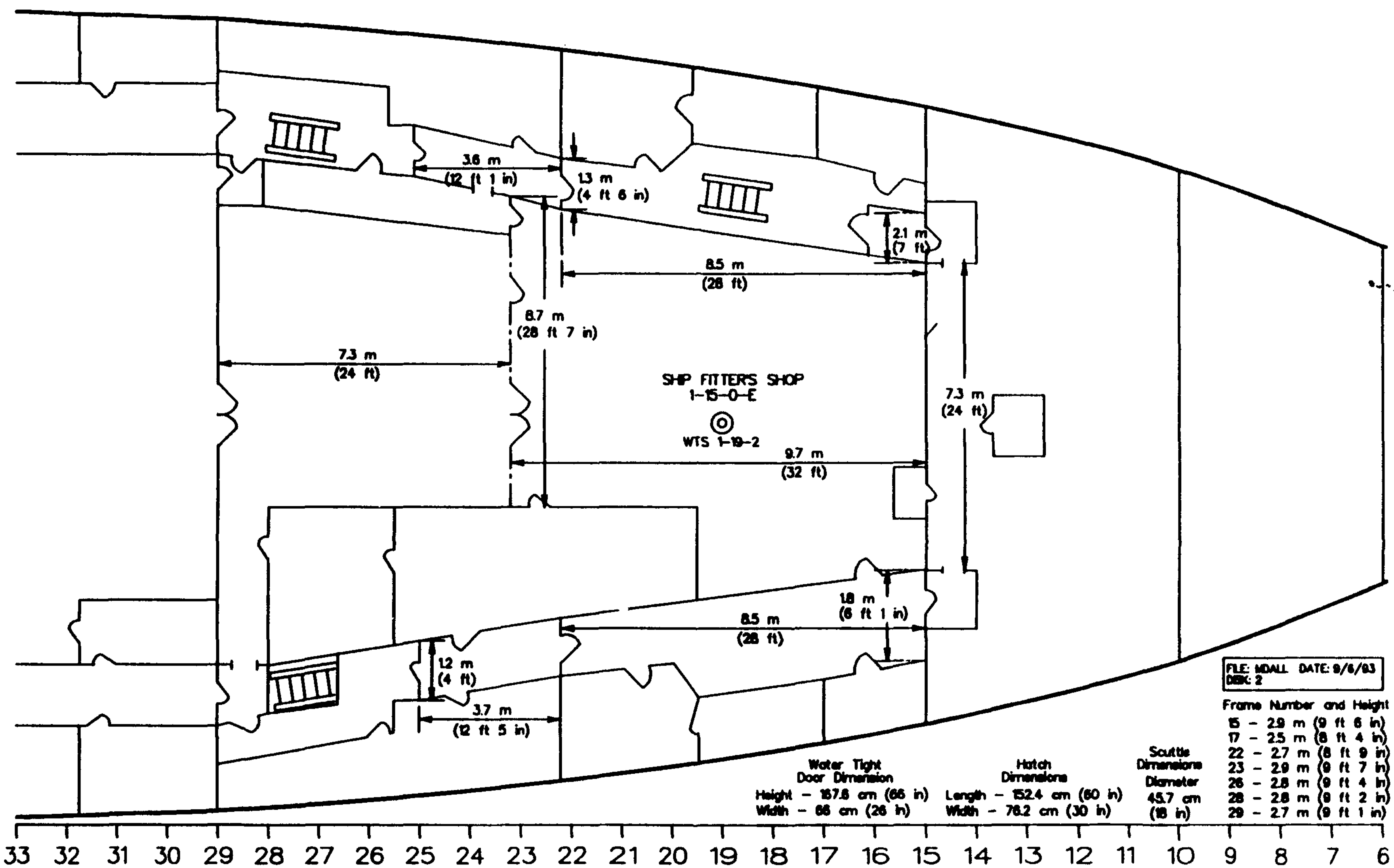

Fig. A1 - Main deck dimensions

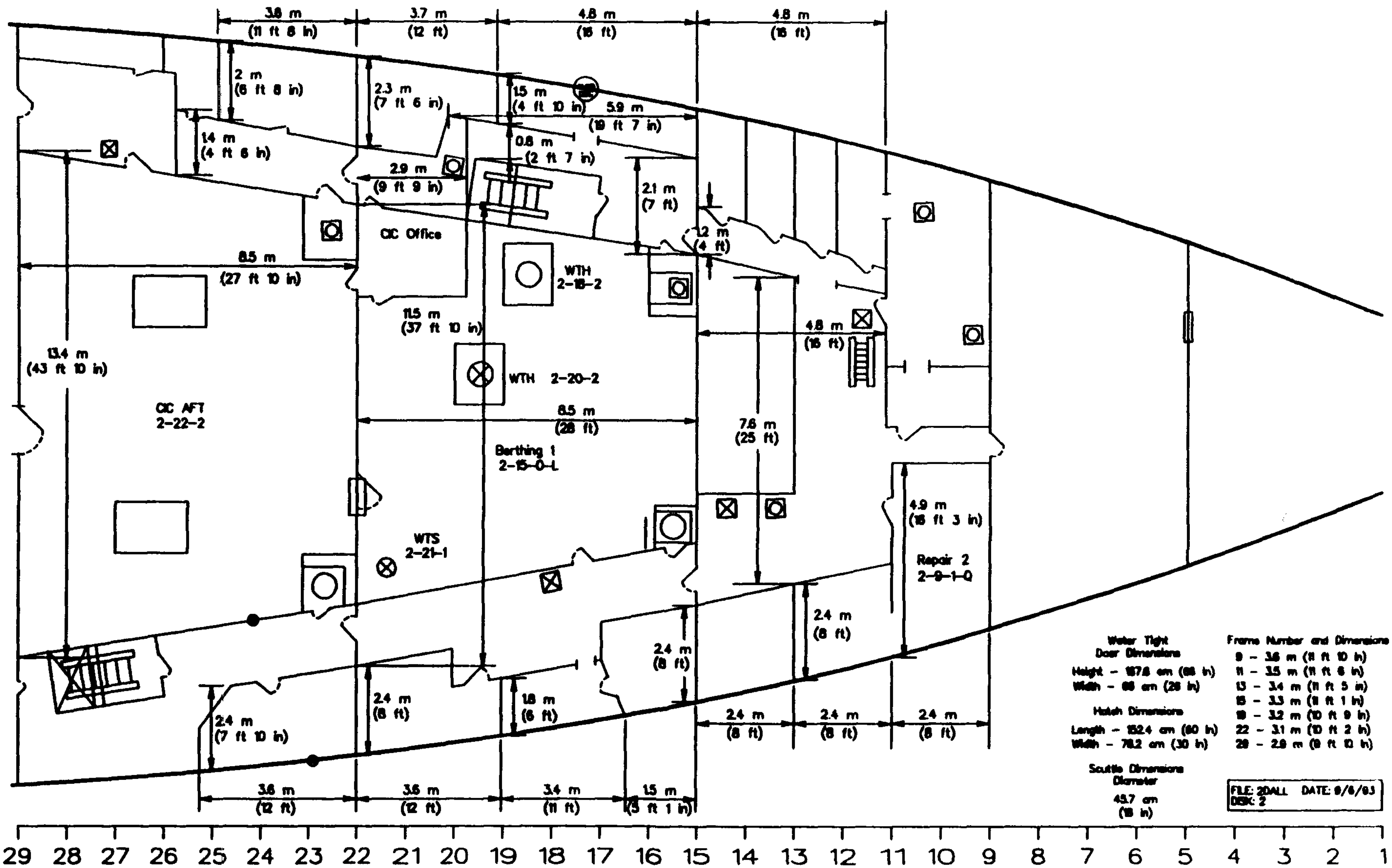

Fig. A2 - Second deck dimensions

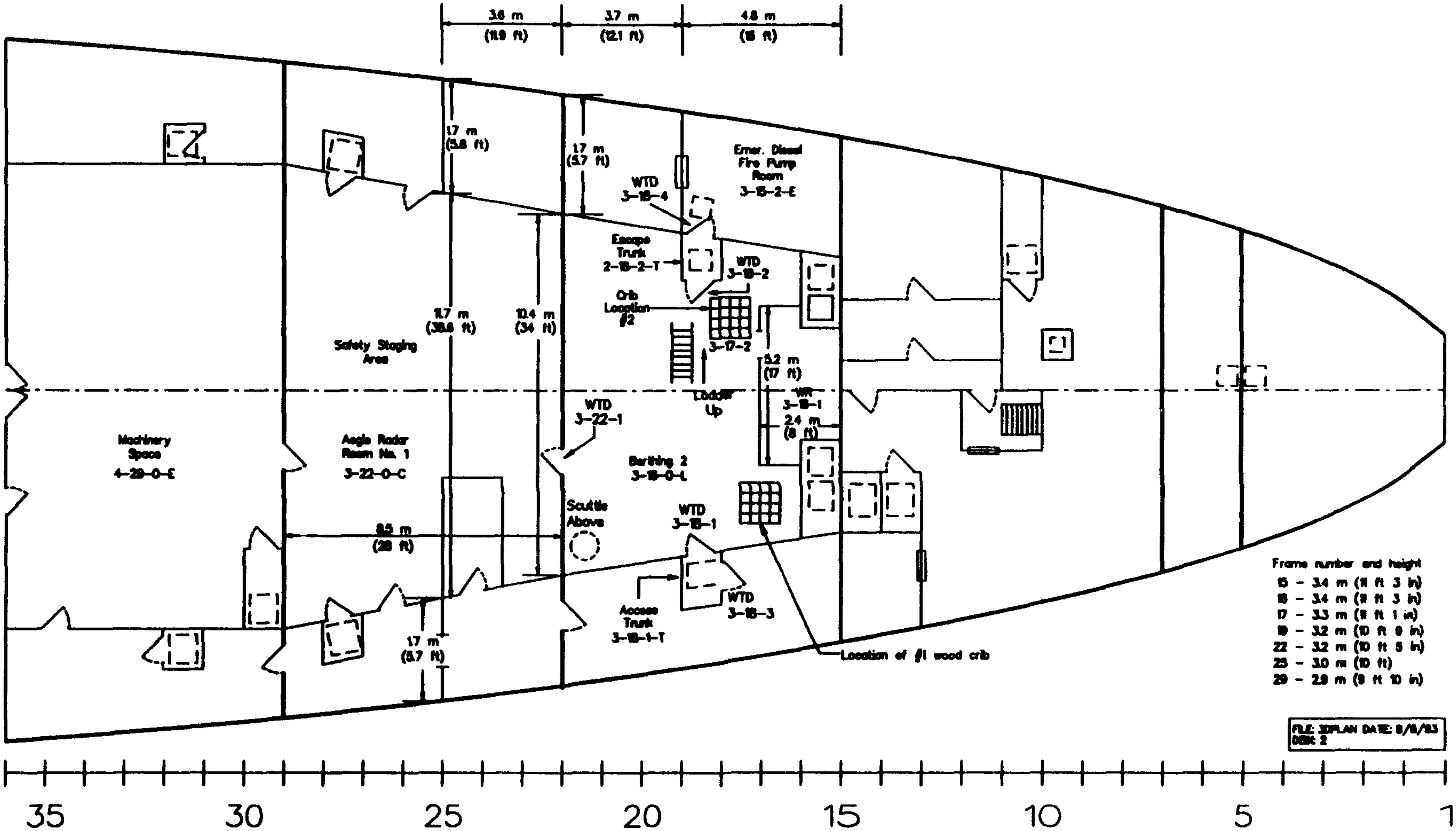

Fig. A3 - Third deck dimensions

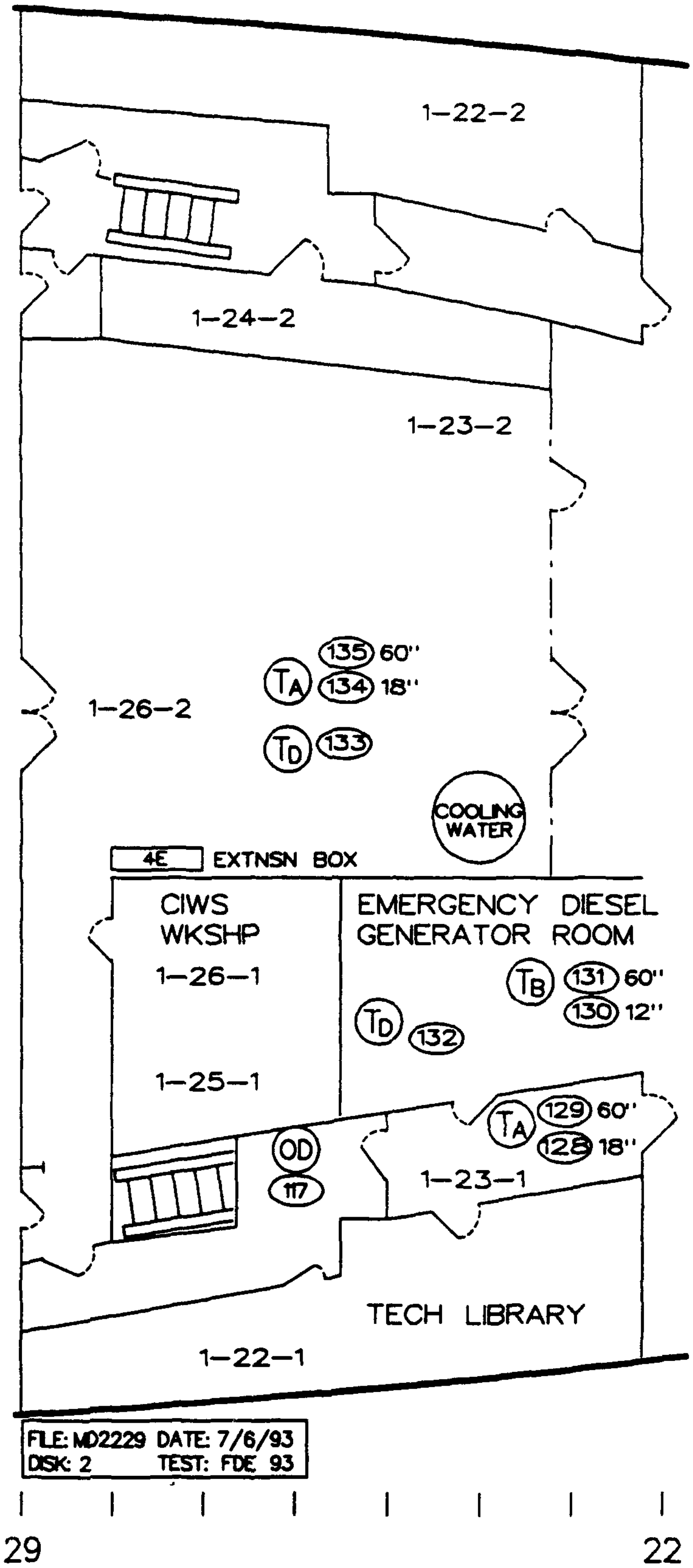

Fig. A4 - Main deck instruments between FR 22-29

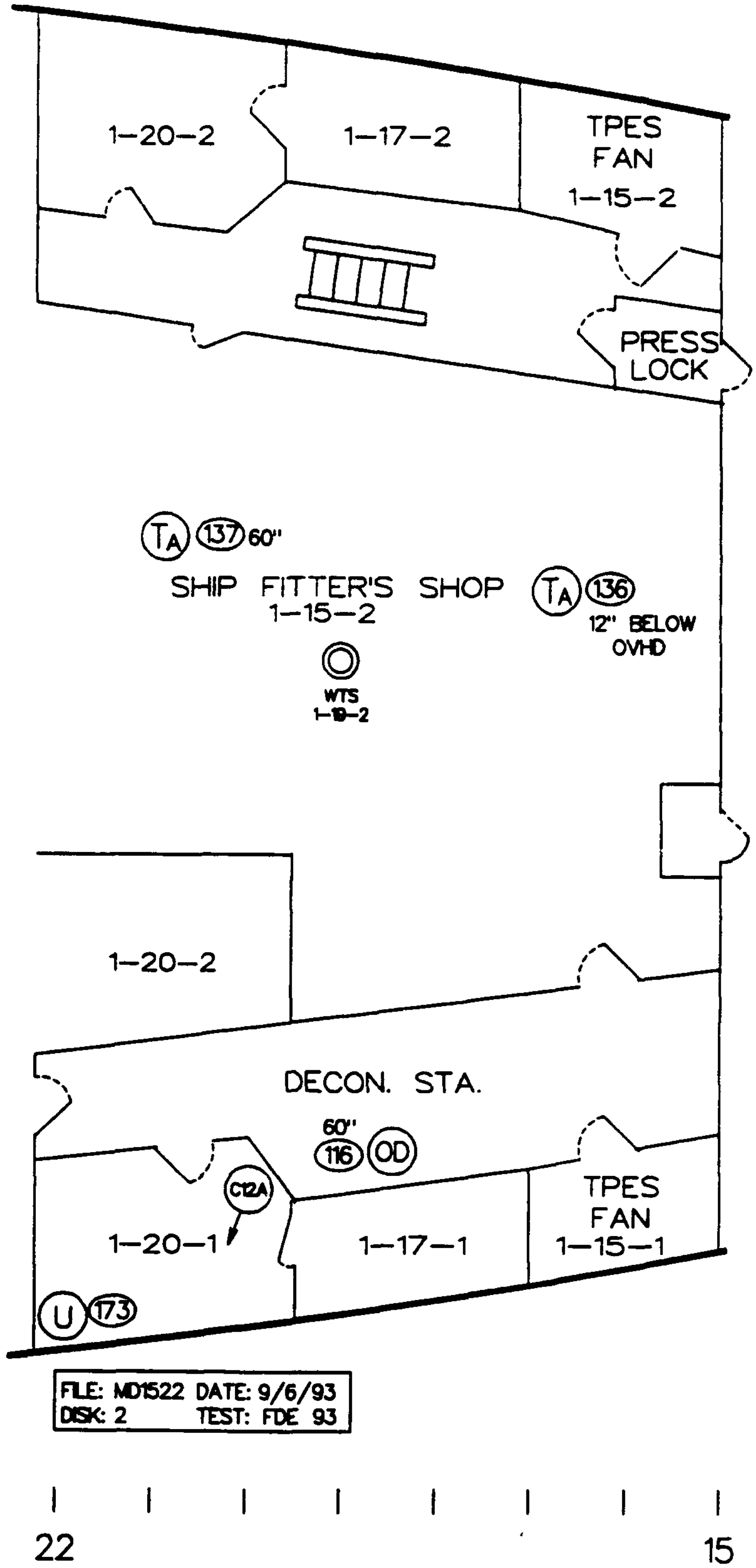

Fig. A5 - Main deck instruments between FR 15-22

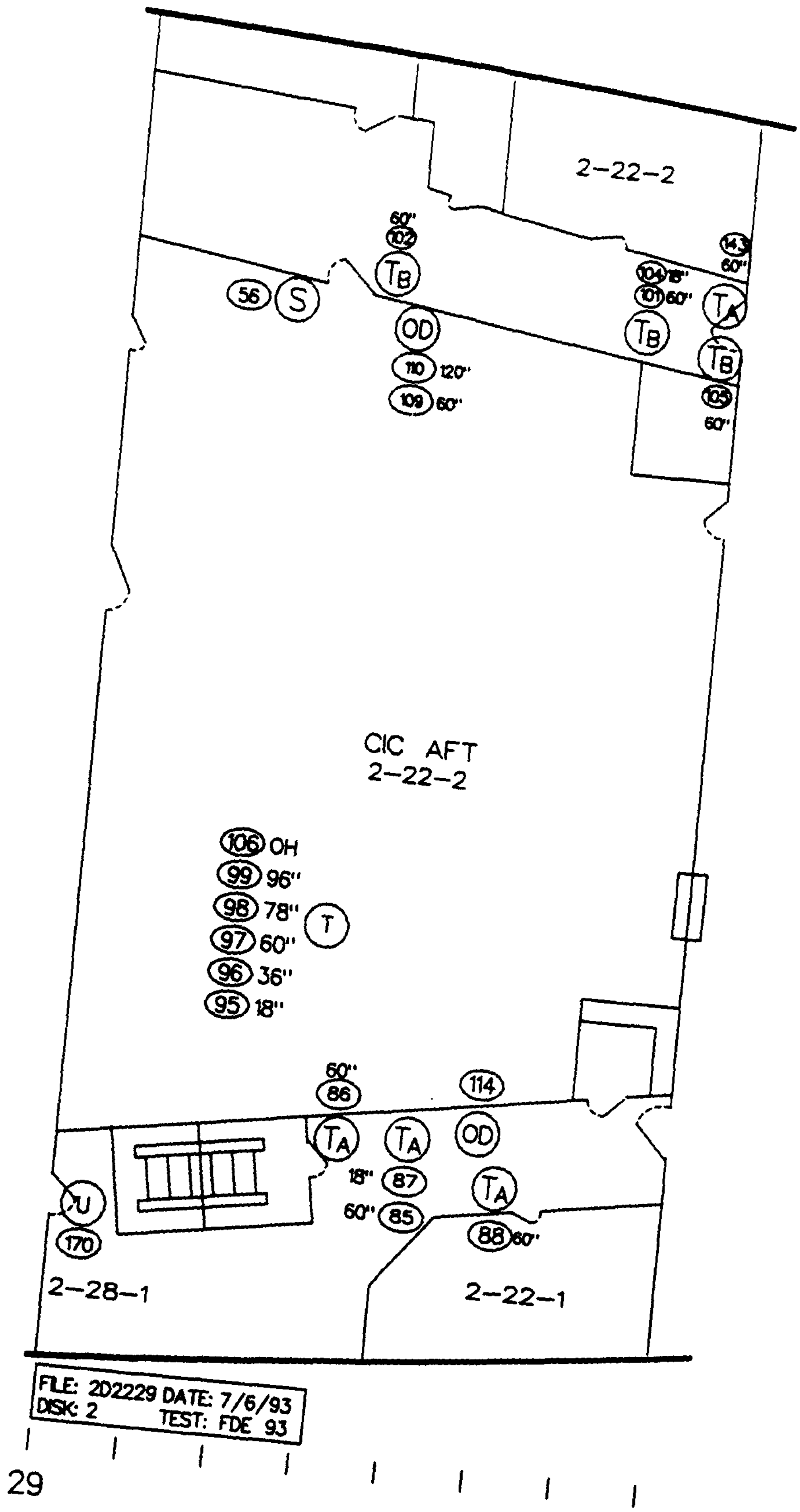

Fig. A6 - Second deck instruments between FR 22-29

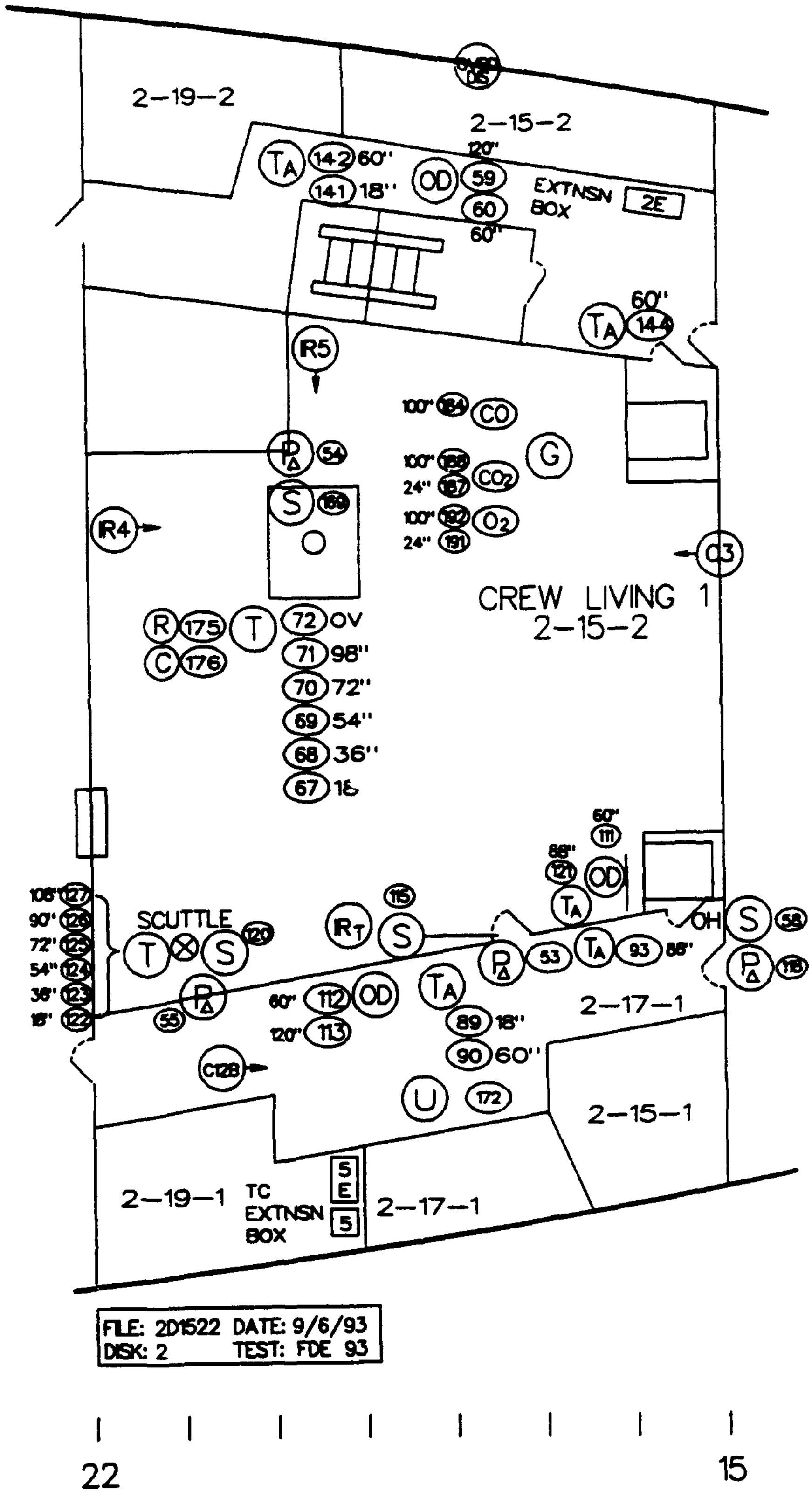

Fig. A7- Second deck instruments between FR 15-22

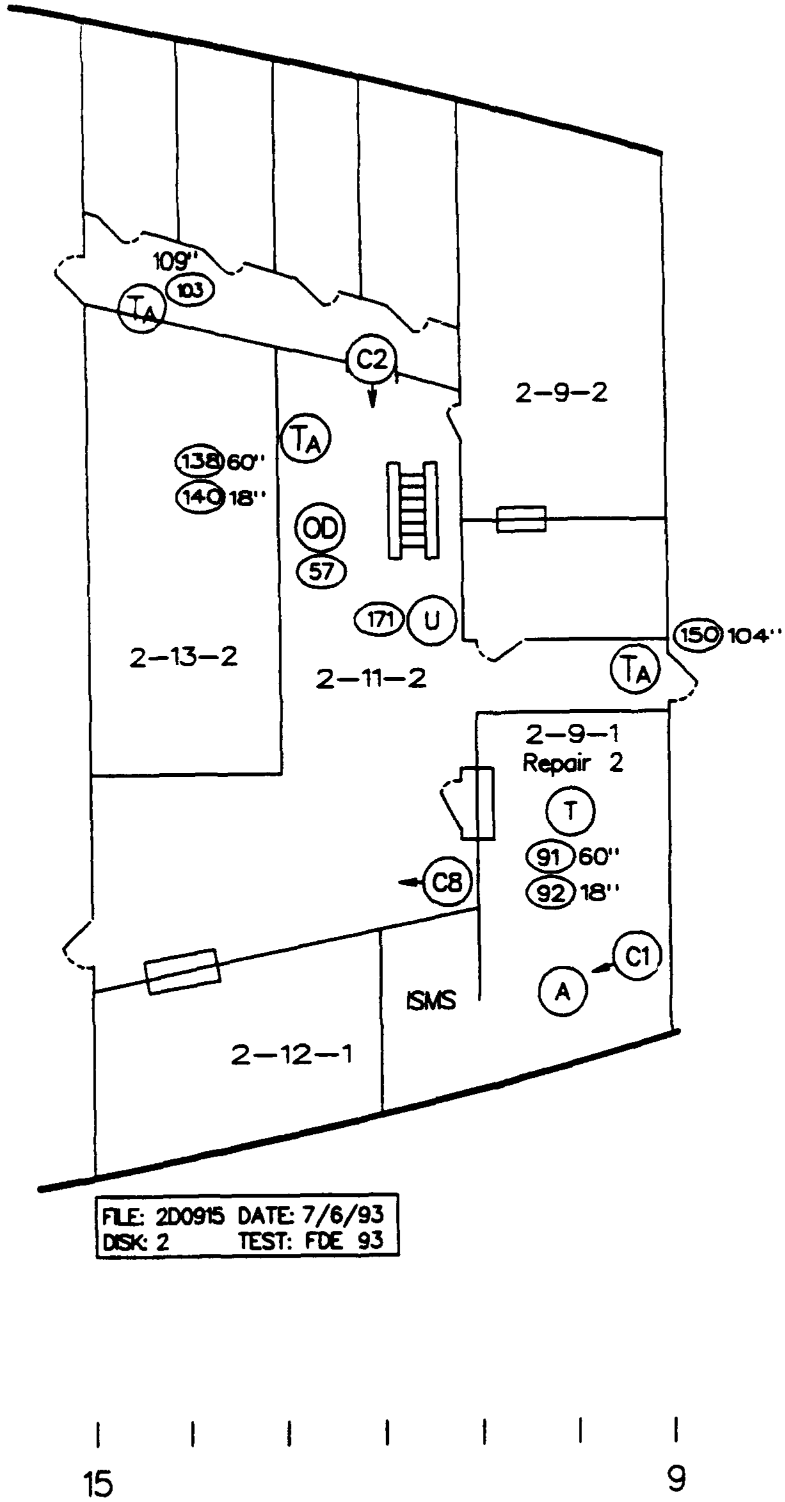

Fig. A8 - Second deck instruments between FR 9-15

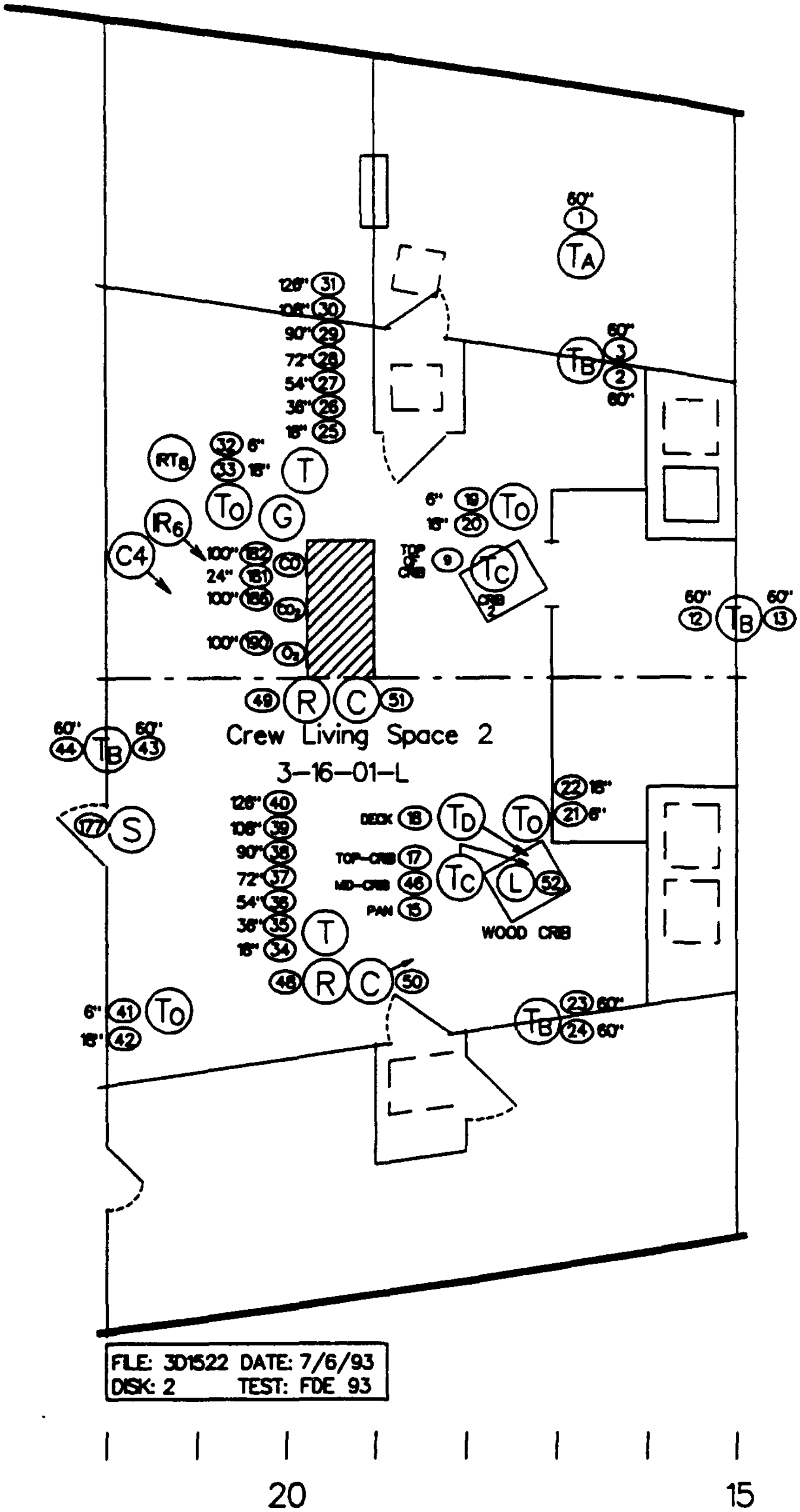

Fig. A9 - Third deck instruments between FR 15-22

APPENDIX B

Representative Data for fd_f3 and fd_f11

FD_F3

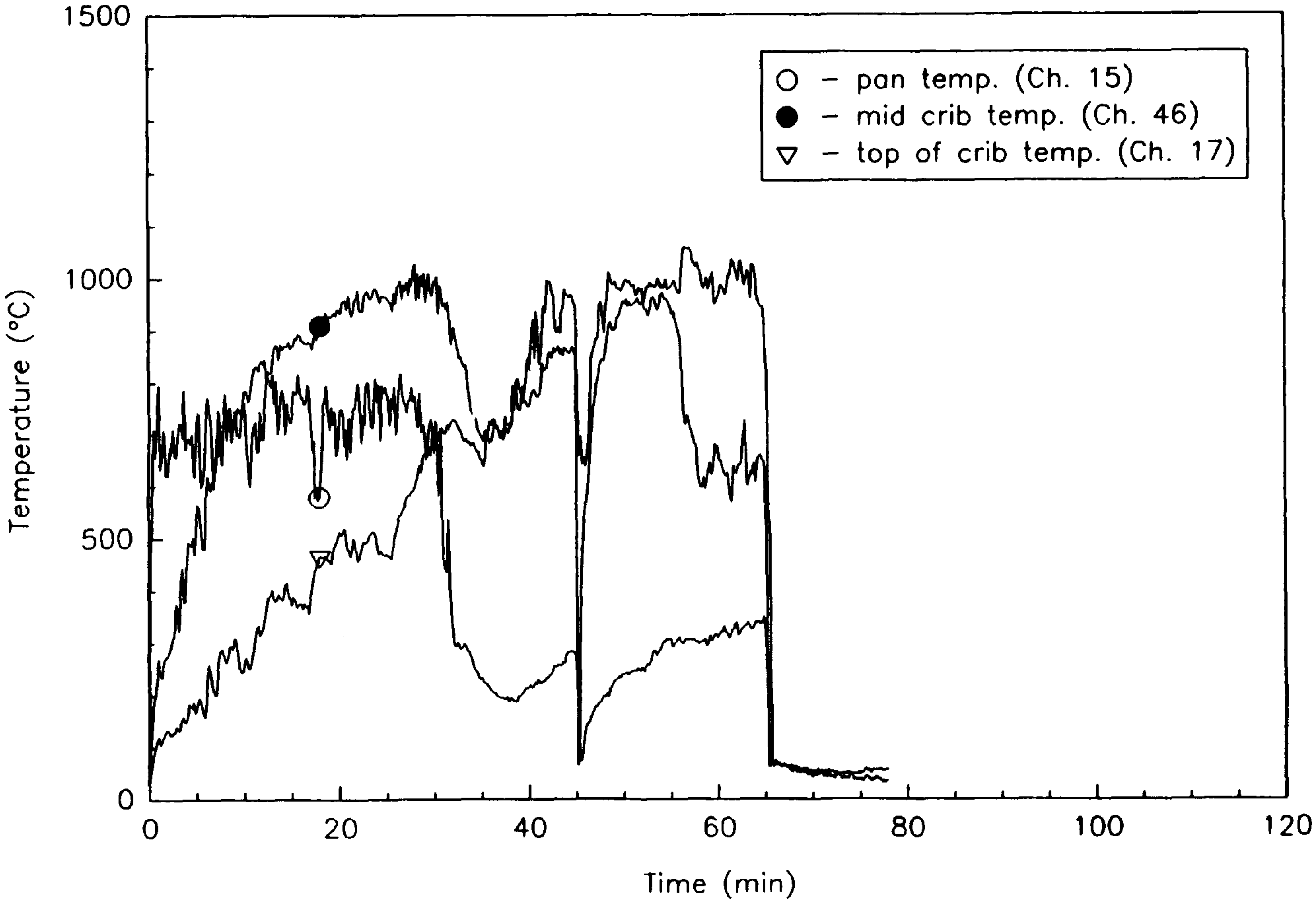

Fig. B1 – Crib #1 temperatures at 3-17-1

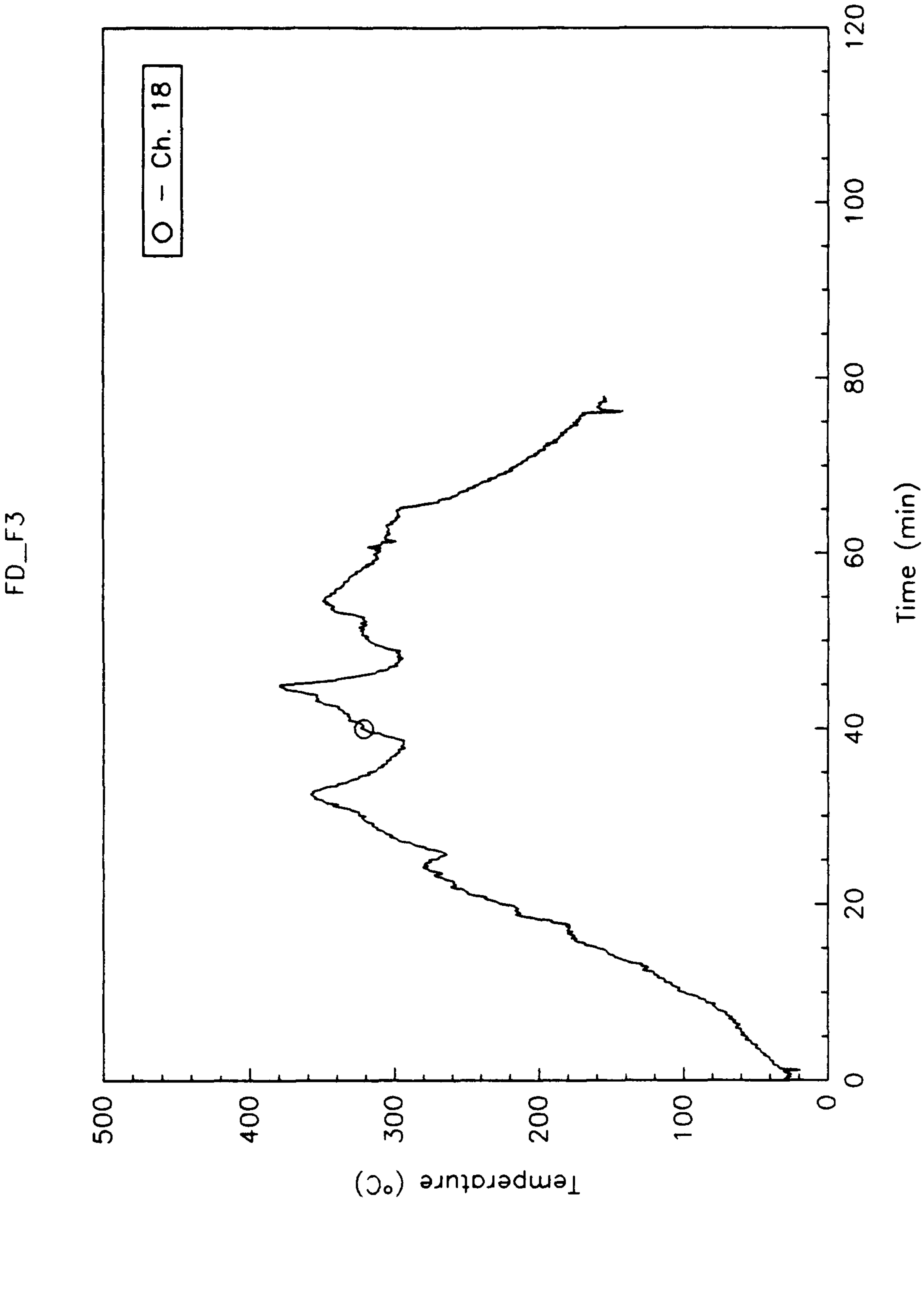

Fig. B2 - Deck temperature at 3-17-1

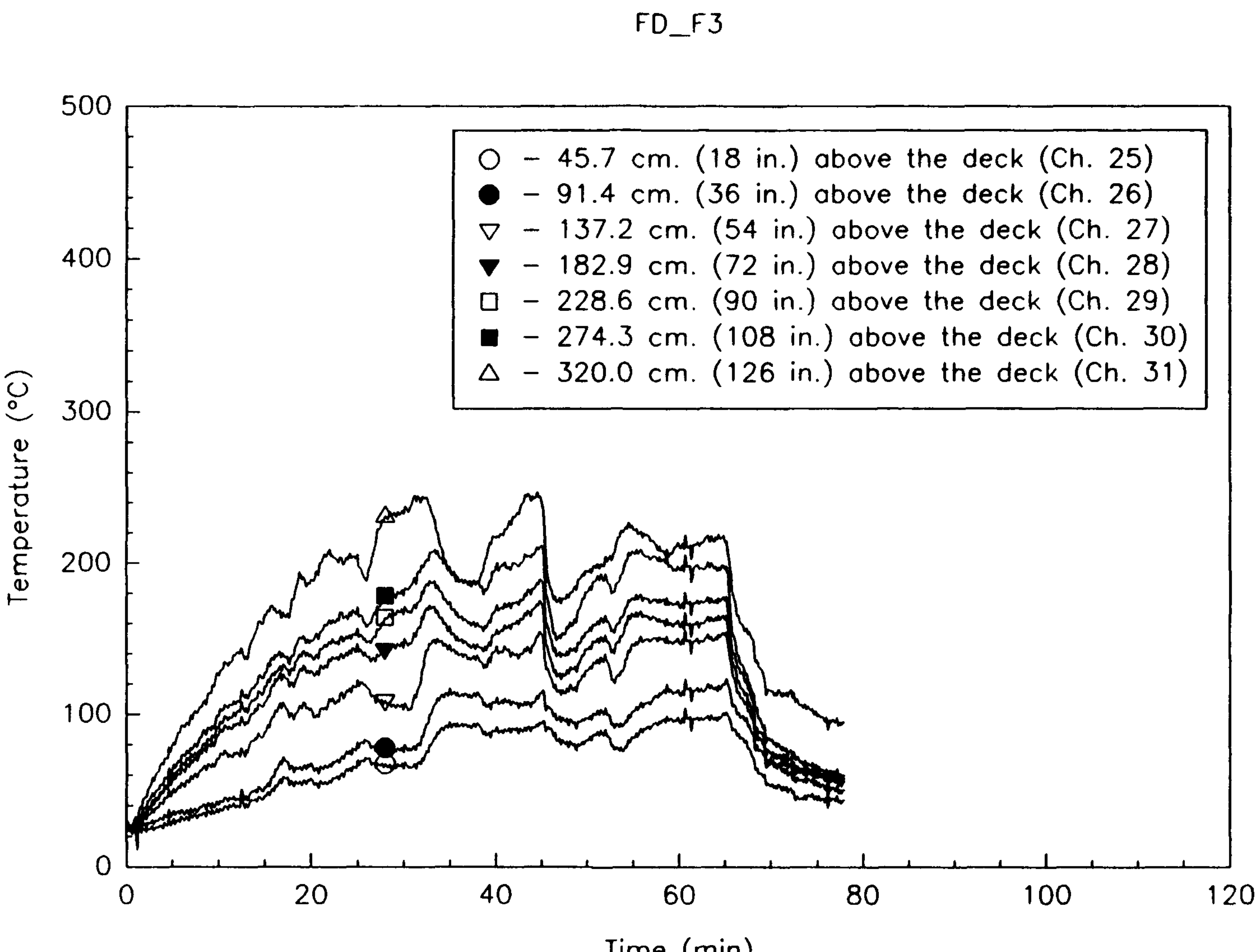

Fig. B3 – Temperature string at 3–20–2

FD_F3

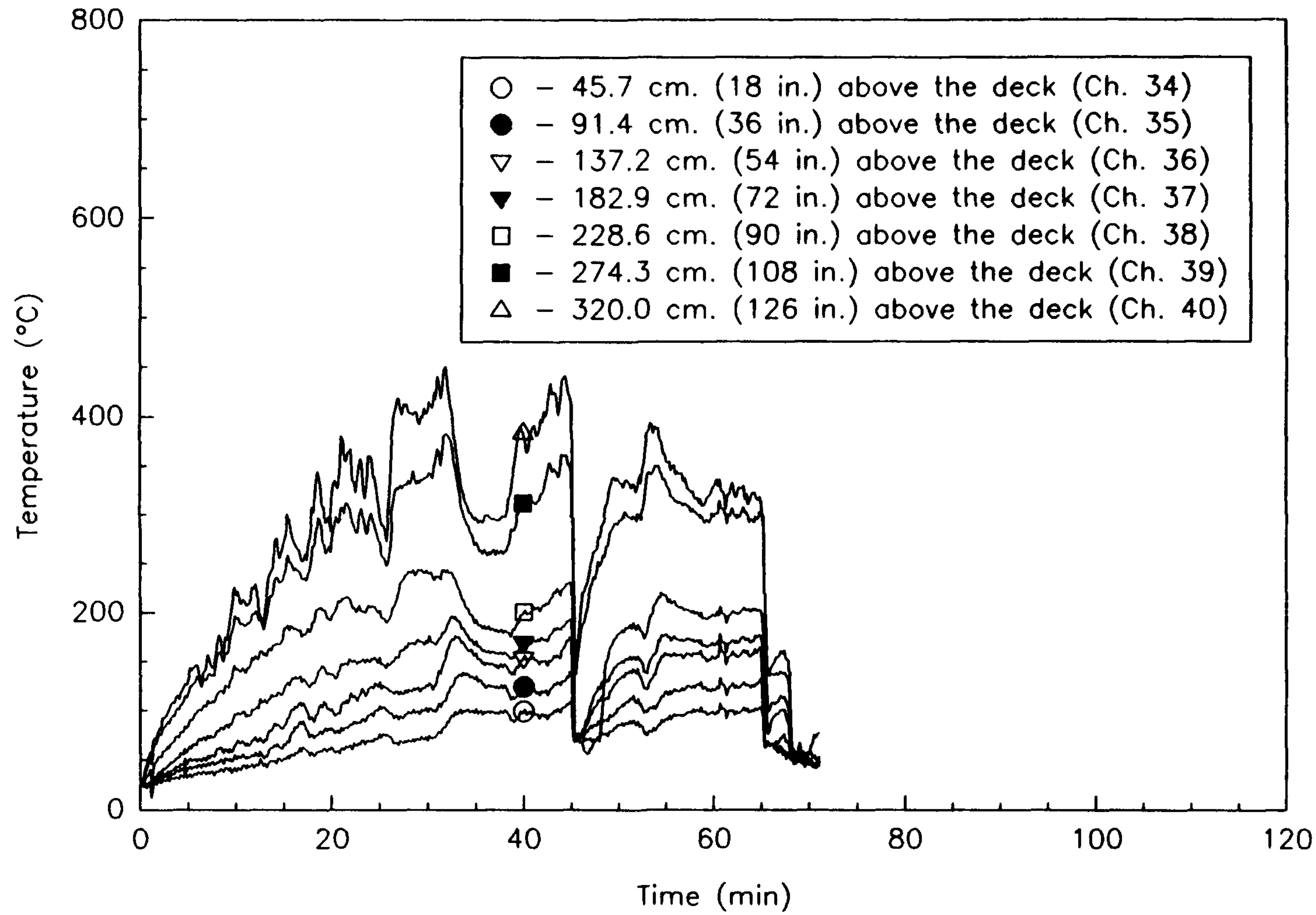

Fig. B4 – Temperature string at 3–20–1

FD_F3

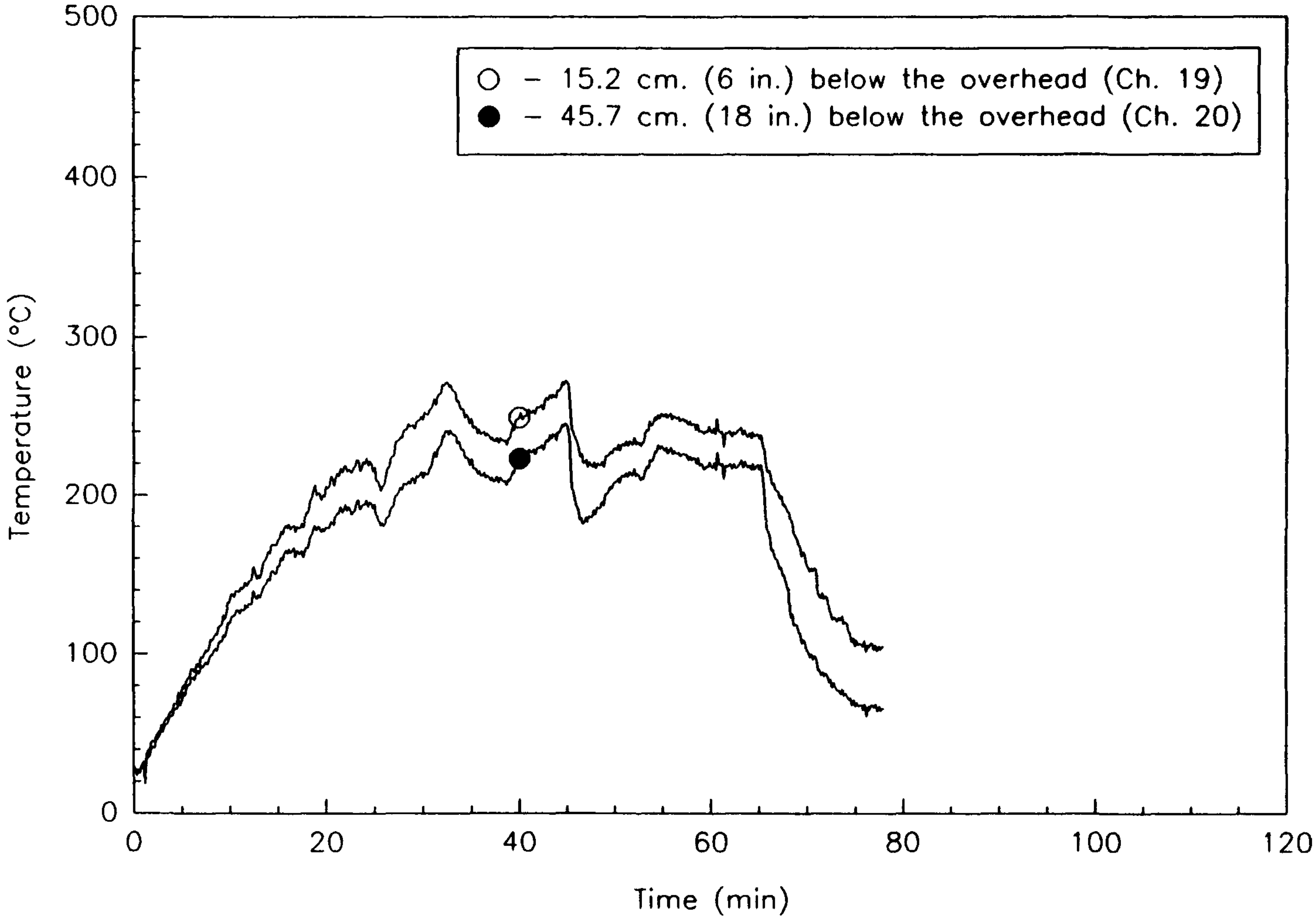

Fig. B5 – Overhead temperatures at 3–17–2

FD_F3

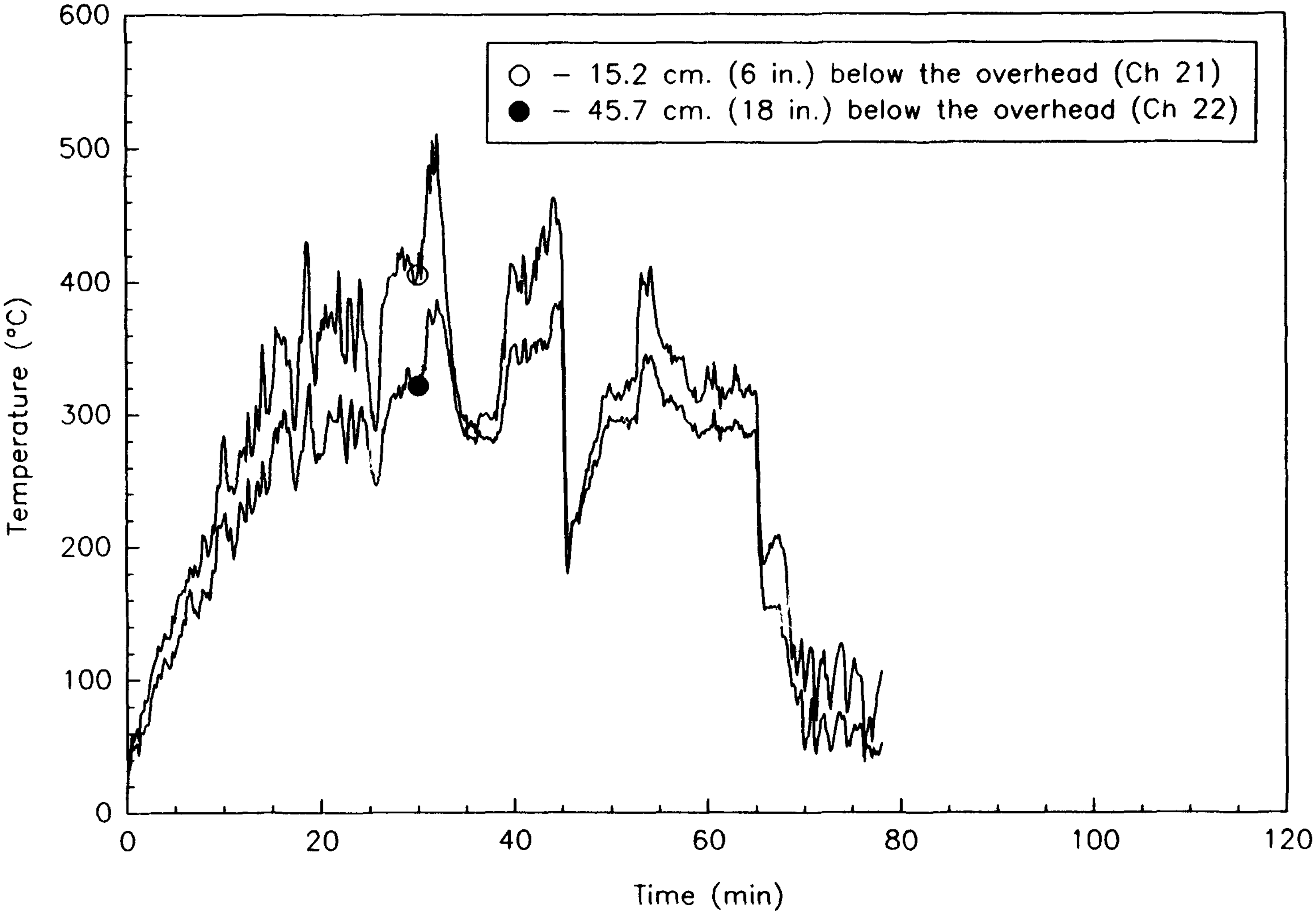

Fig. B6 – Overhead temperatures at 3–17–1

FD_F3

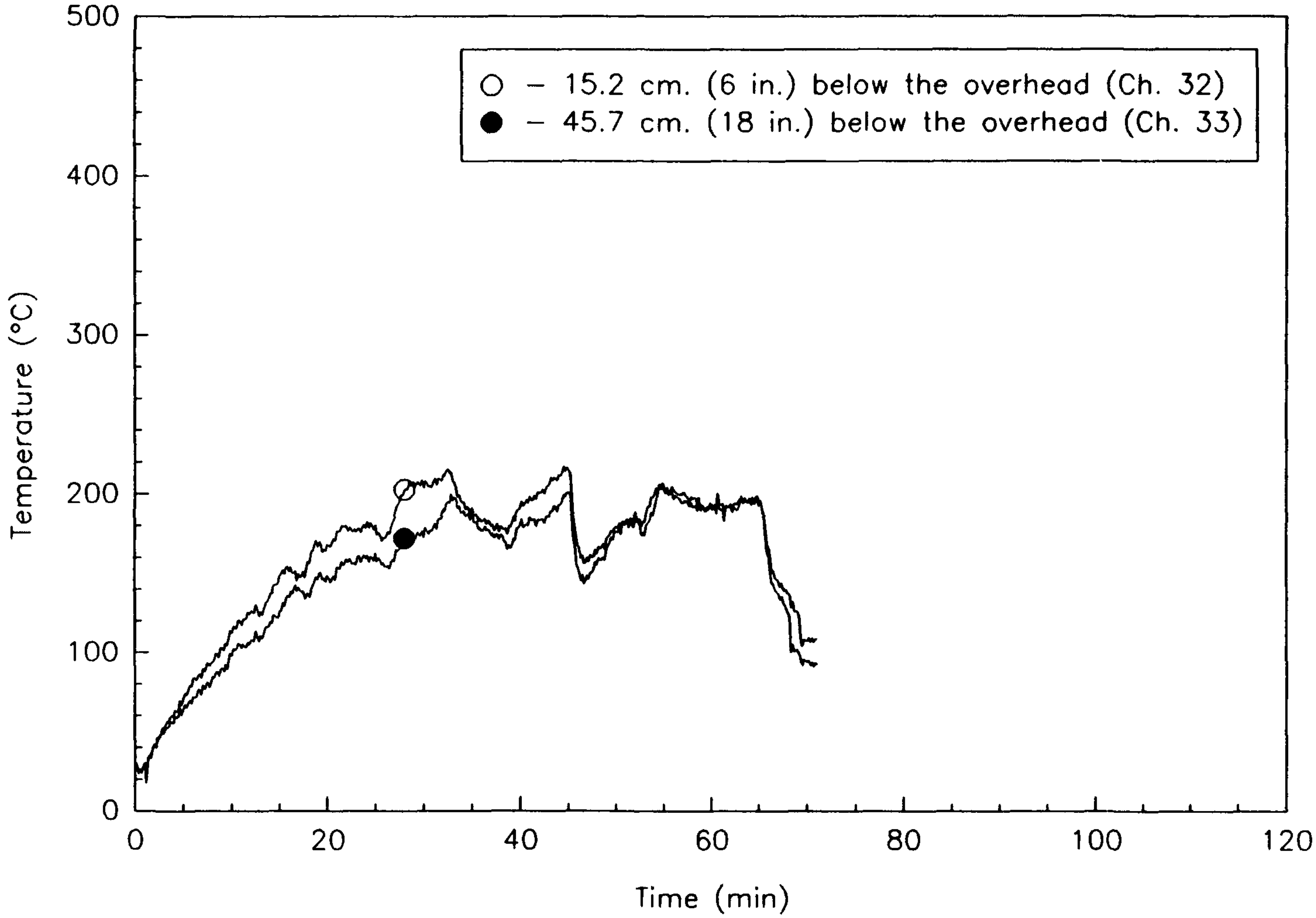

Fig. B7 – Overhead temperatures at 3–21–2

FD_F3

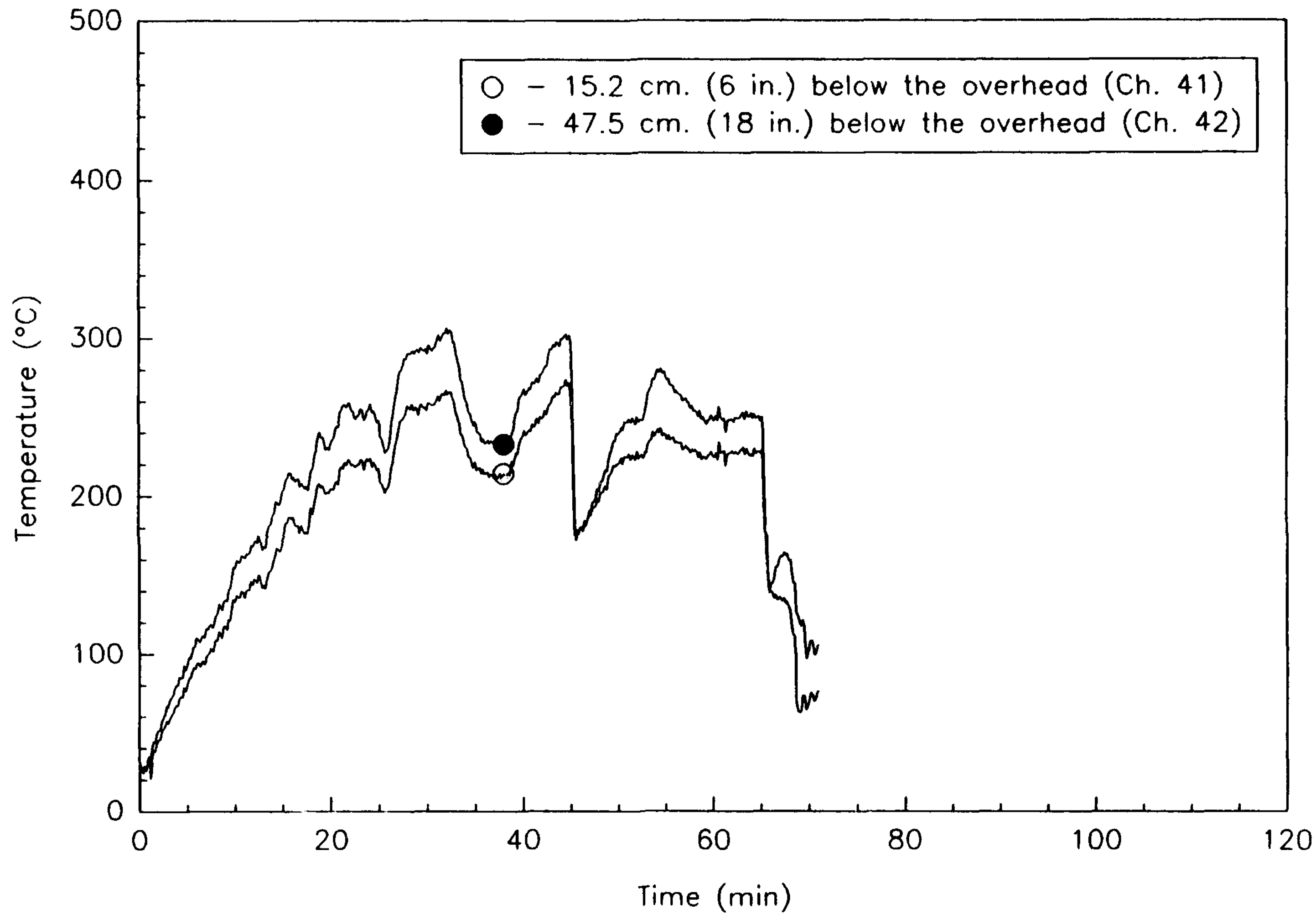

Fig. B8 – Overhead temperatures at 3–21–1

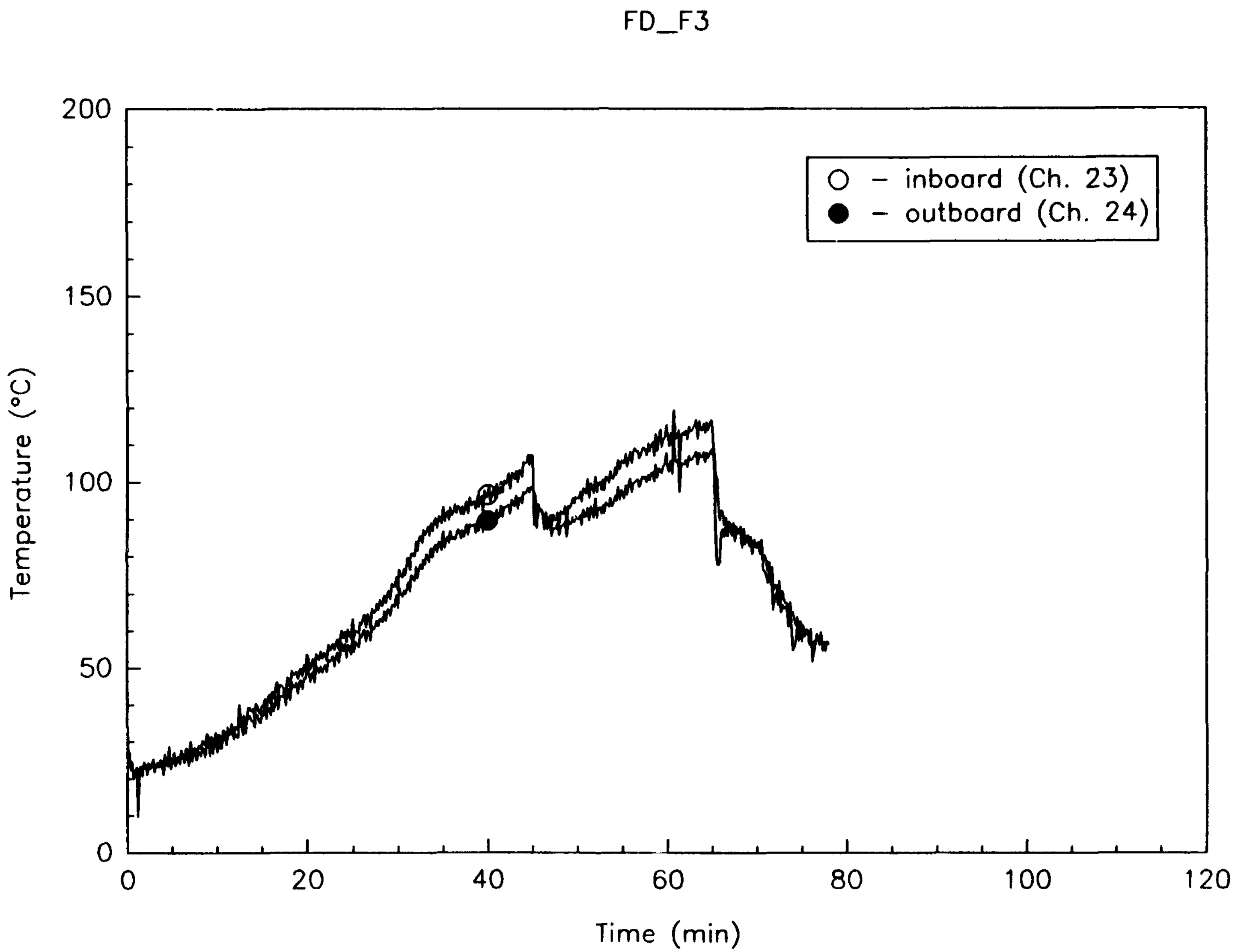

Fig. B9 – Bulkhead temperatures at 3–17–1 152.4 cm. (60 in.) above the deck

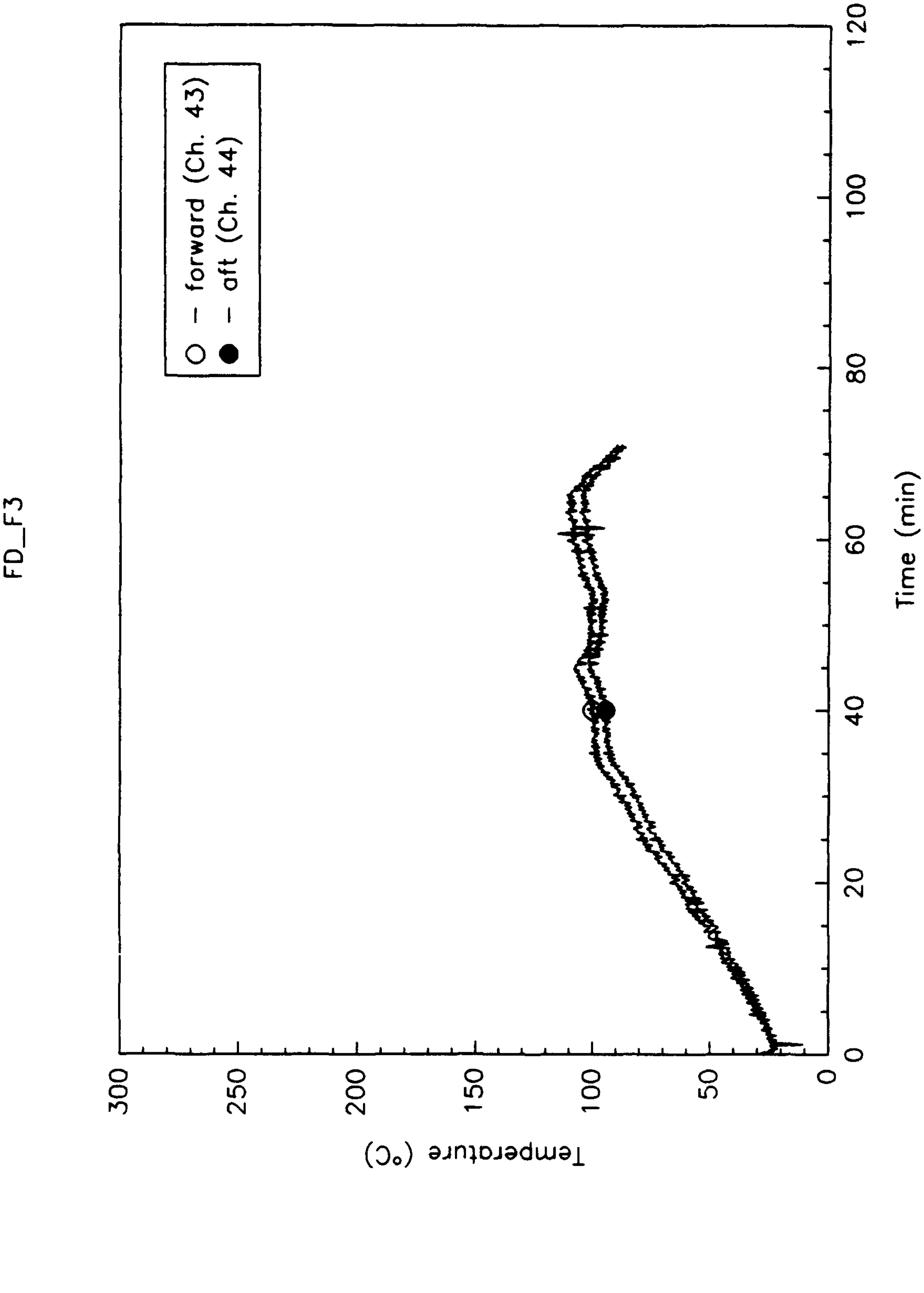

Fig. B10 – Bulkhead temperature at 3–22–0 152.4 cm. (60 in.) above the deck

FD_F3

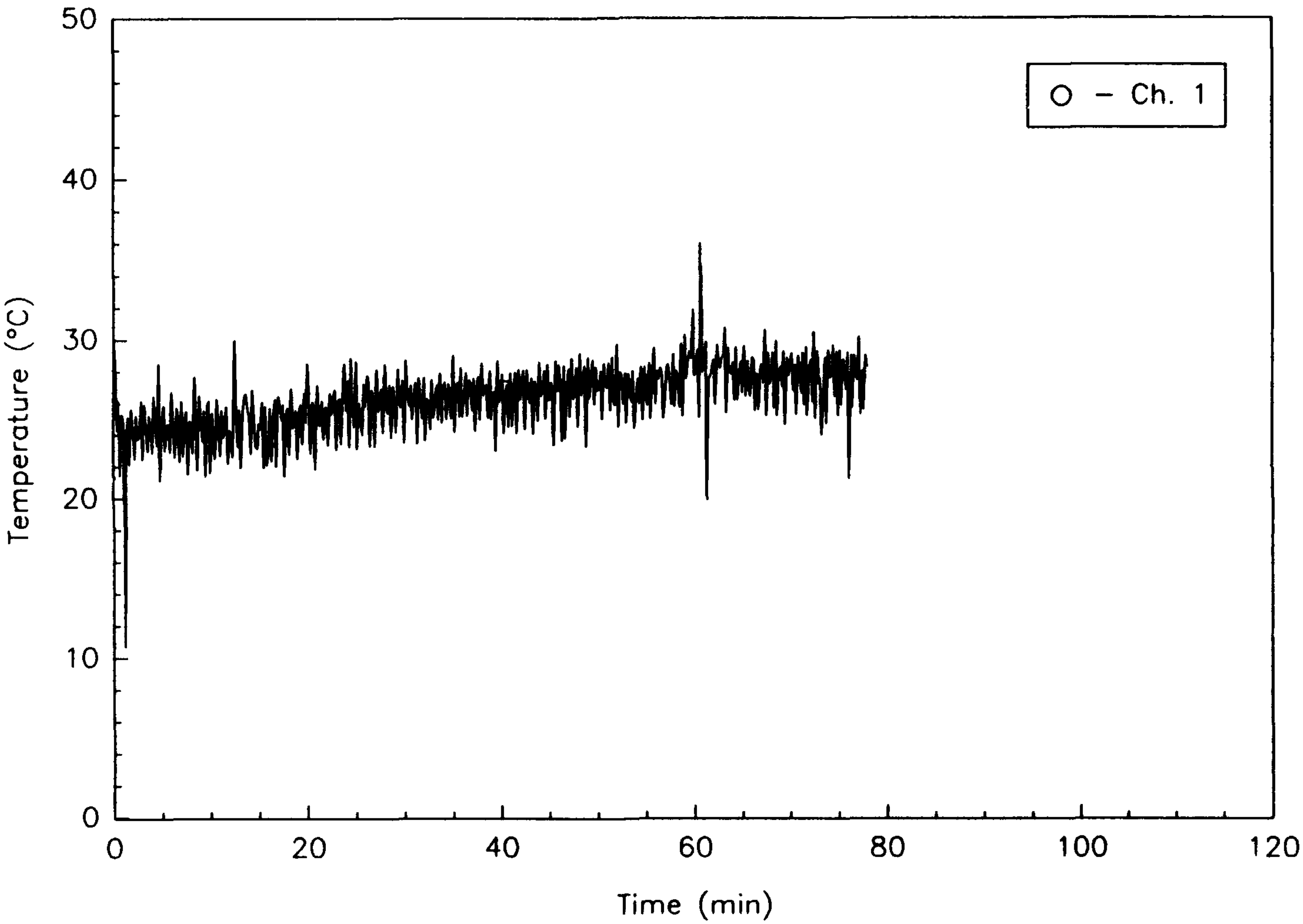

Fig. B11 – Air temperature at 3–16–2 152.4 cm. (60 in.)above the deck
(above Emergency Diesel Fire Pump)

FD_F3

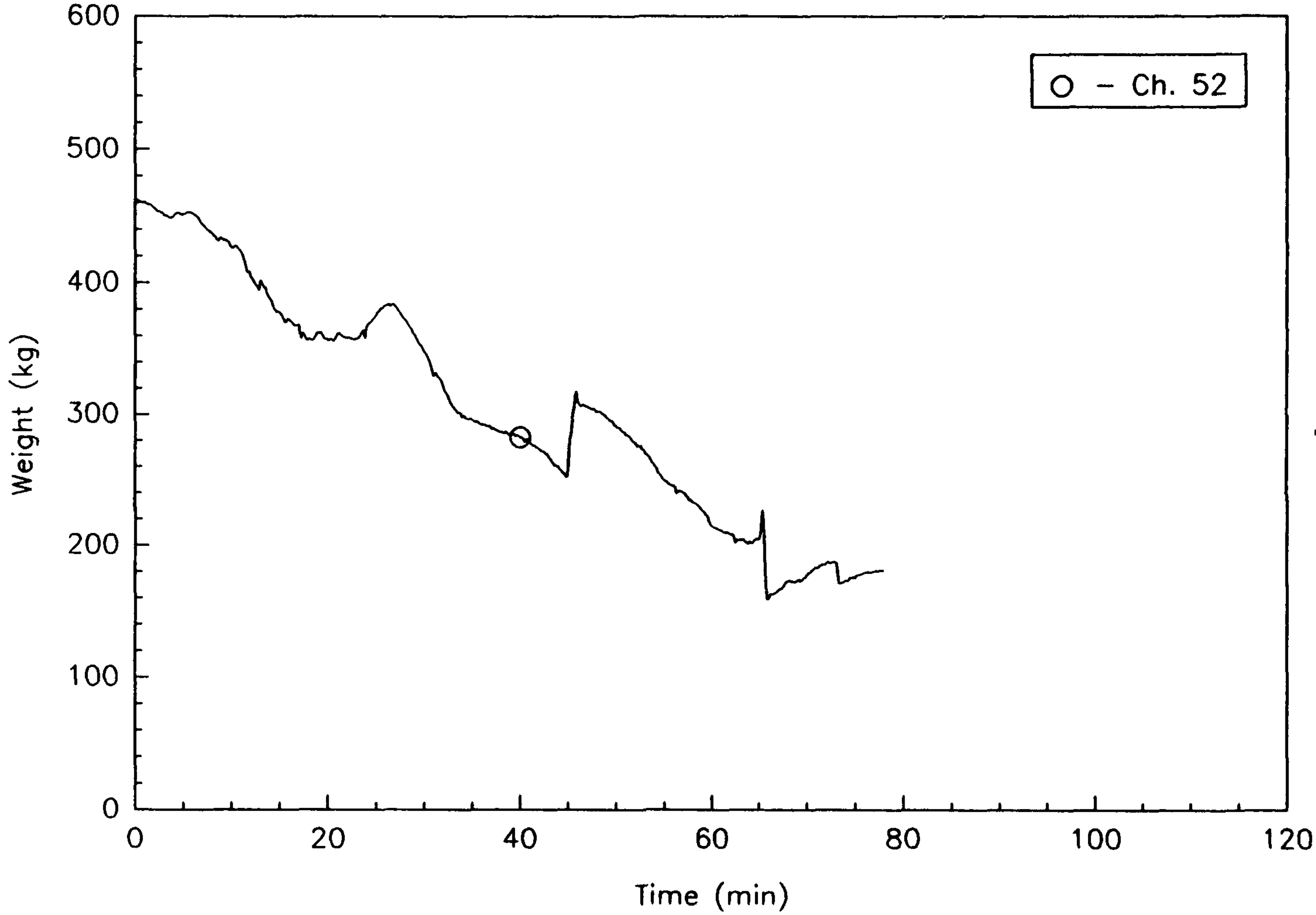

Fig. B12 – Crib #1 weight at 3–17–1

FD_F3

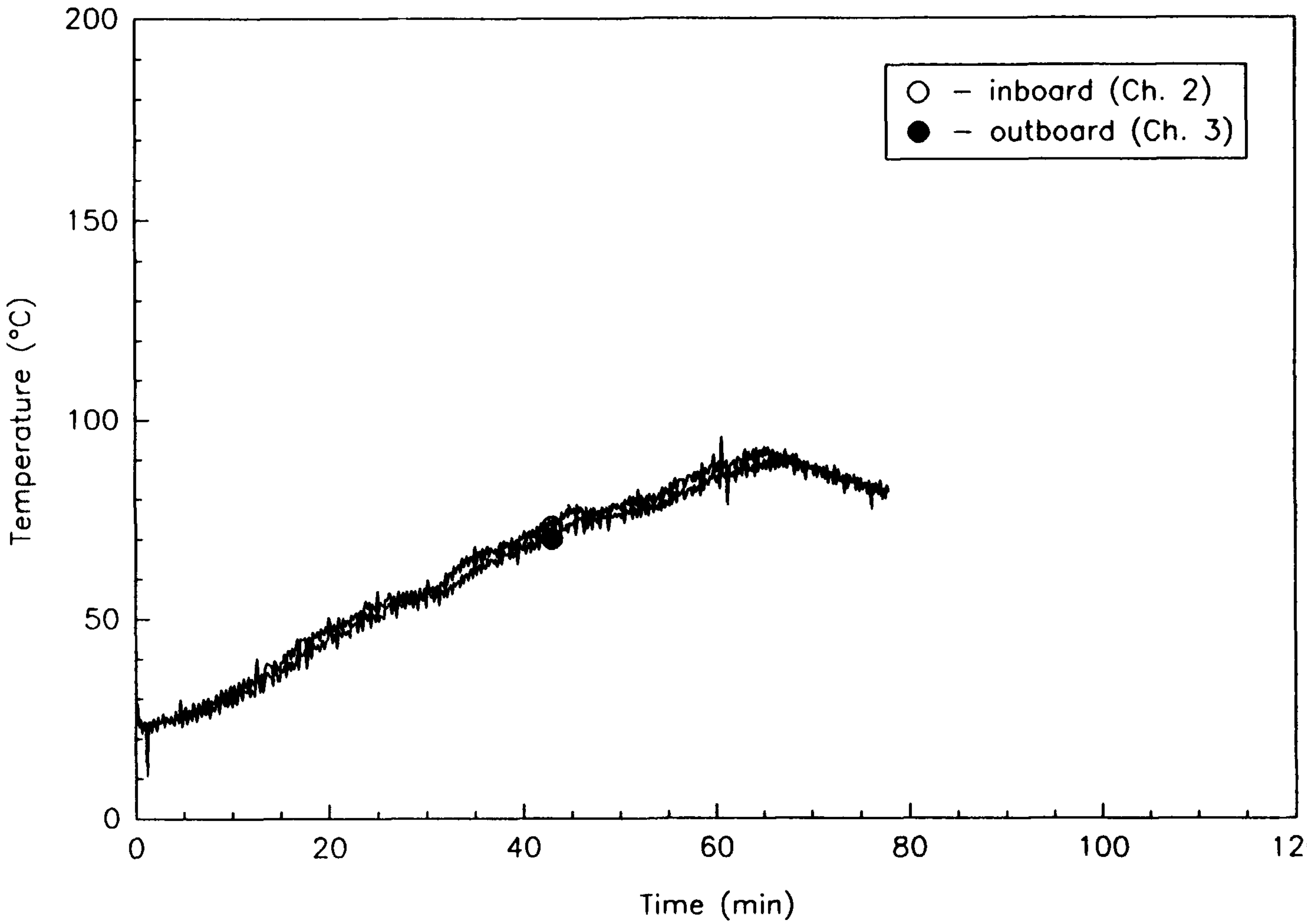

Fig. B13 – Bulkhead temperatures at 3–16–2 152.4 cm. (60 in.) above the deck

FD_F3

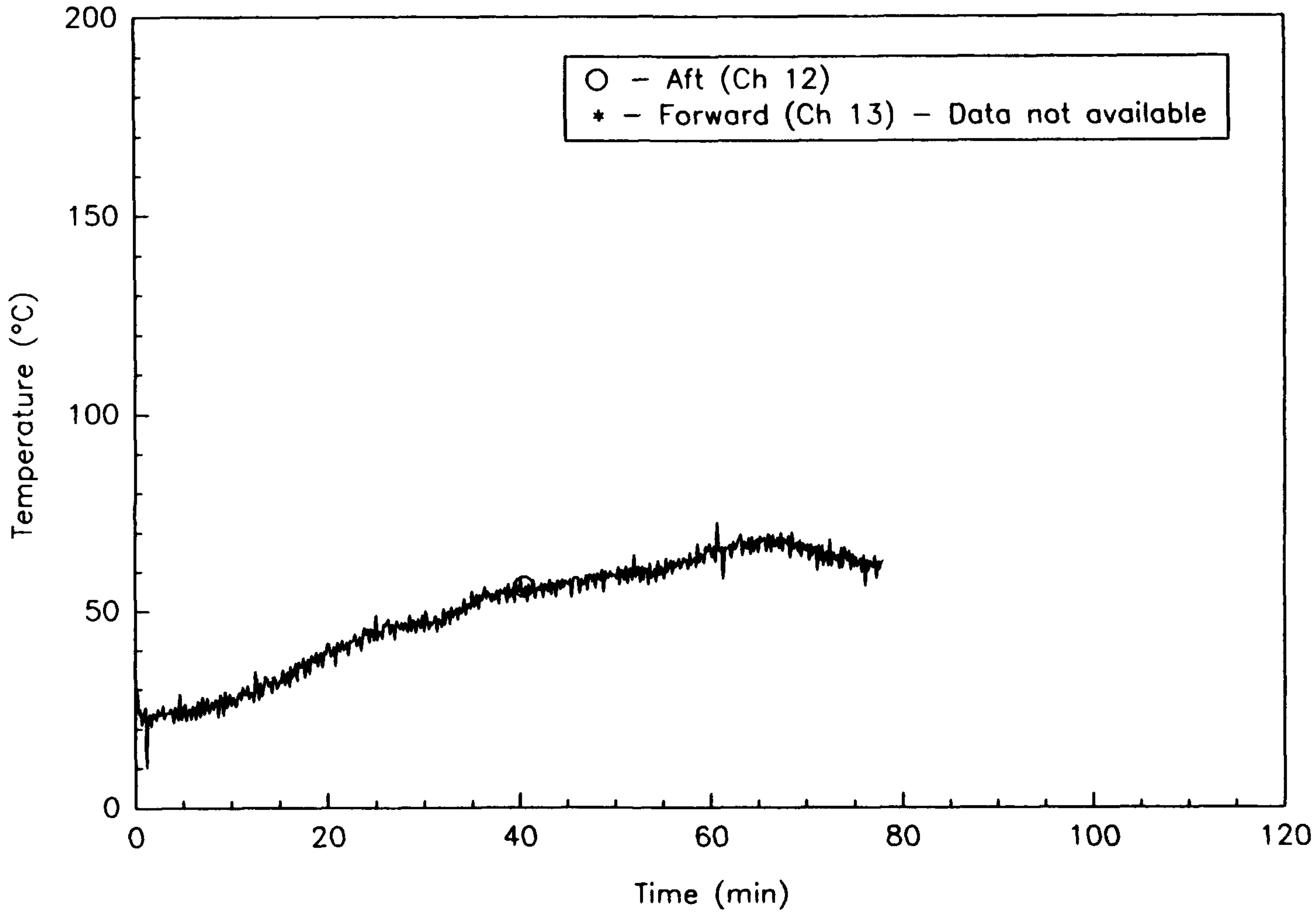

Fig. B14 – Bulkhead temperatures at 3–15–0 152.4 cm. (60 in.) above the deck

FD_F3

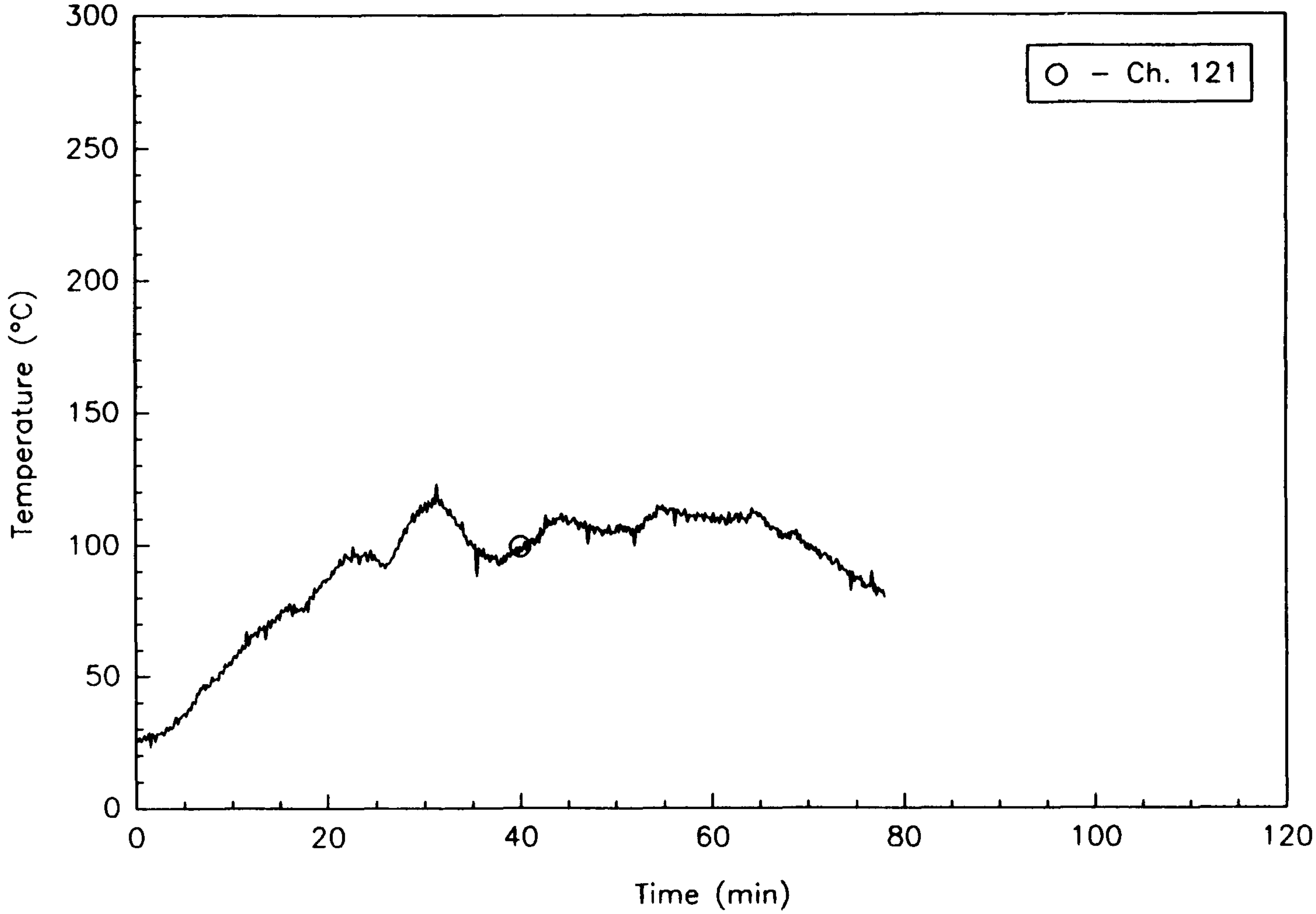

Fig. B15 – Air temperature at 2–16–1 in Crew Living 1
304.8 cm. (120 in.) above the deck

FD_F3

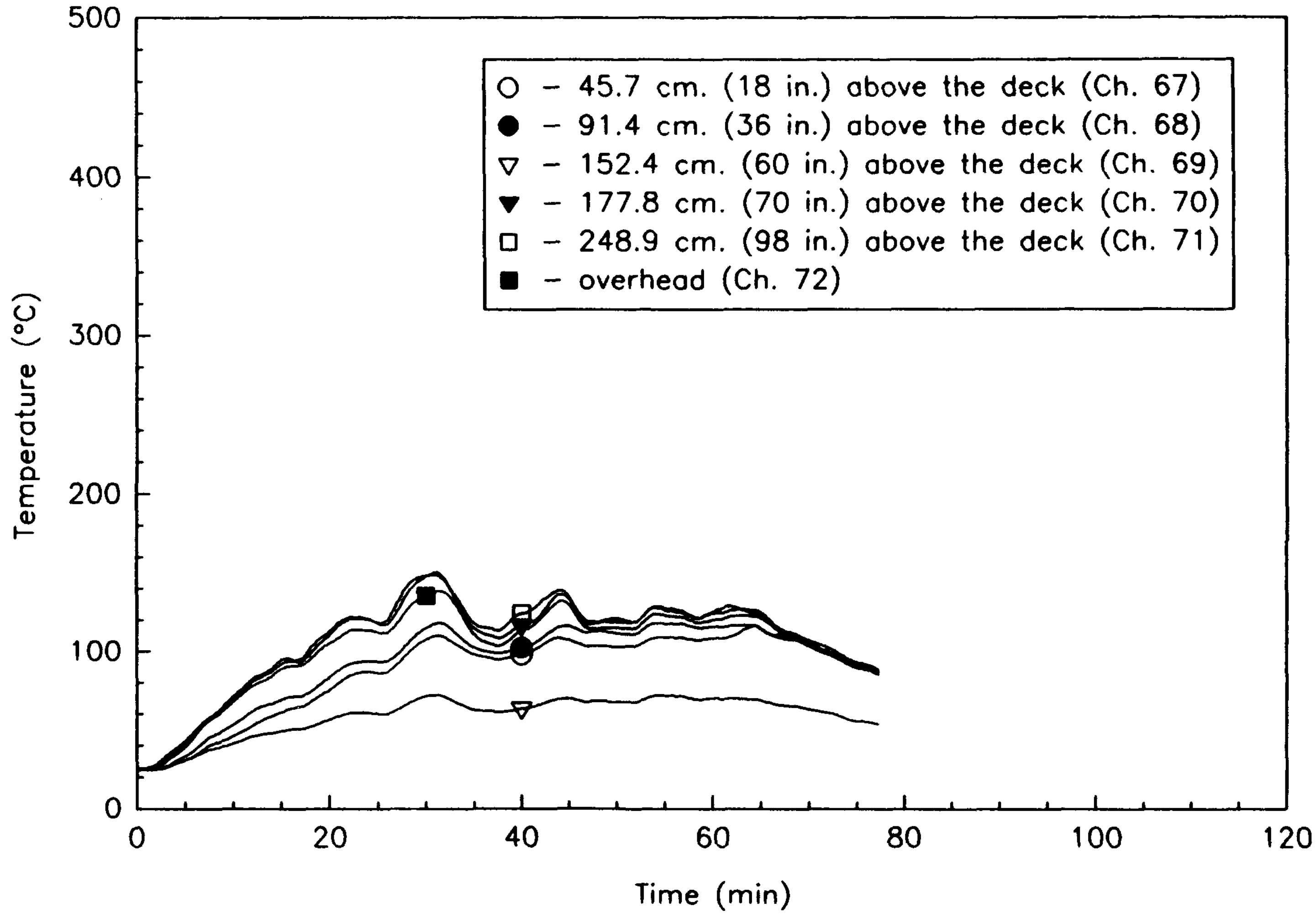

Fig. B16 – Temperature string at 2–20–0

FD_F3

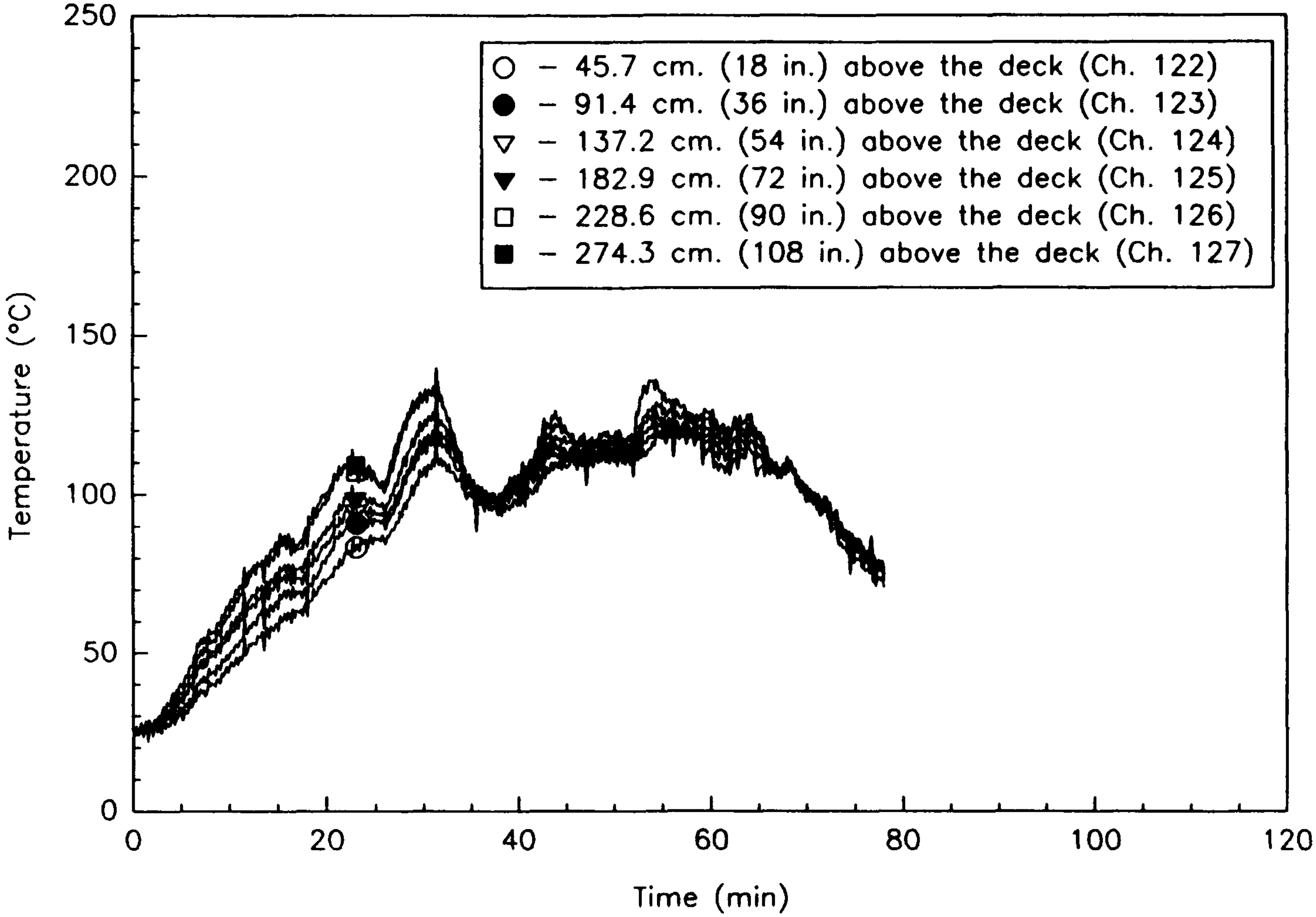

Fig. B17 – Temperature string at 2–21–1 in Crew Living 1

FD_F3

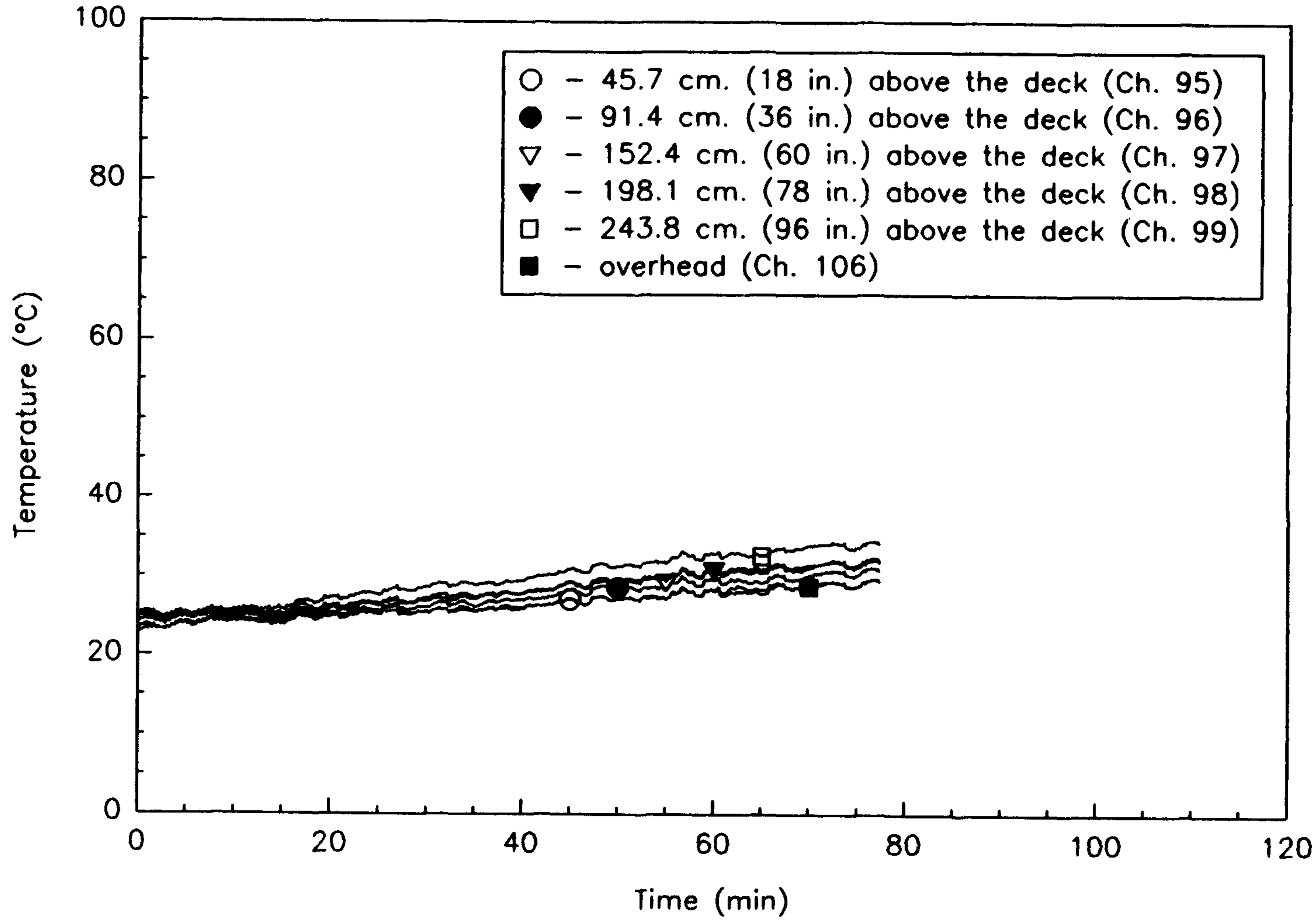

Fig. B18 – Temperature string at 2-25-2 in CIC AFT

FD_F3

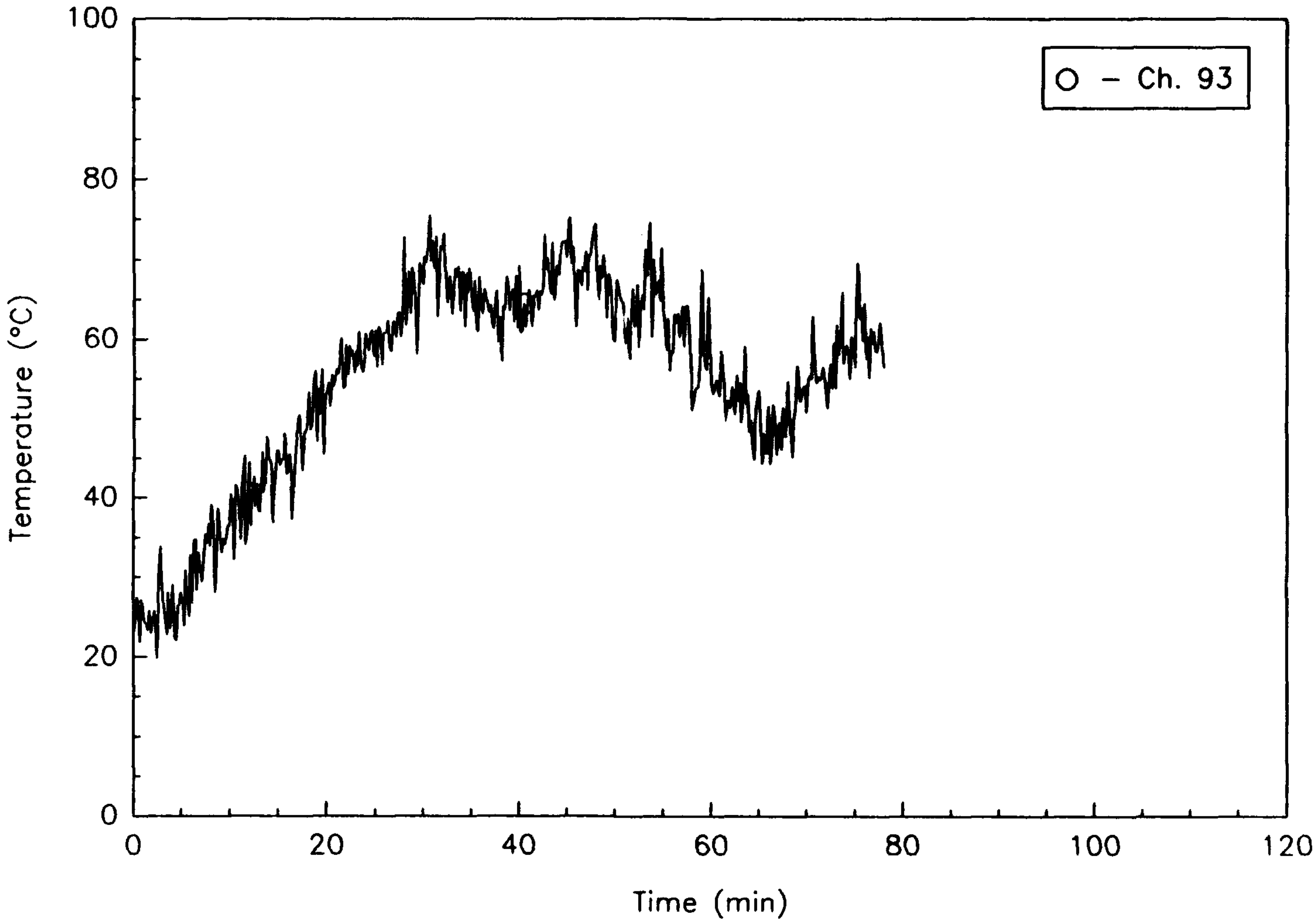

Fig. B19 – Lintel temperature at QAWTD 2-17-1

FD_F3

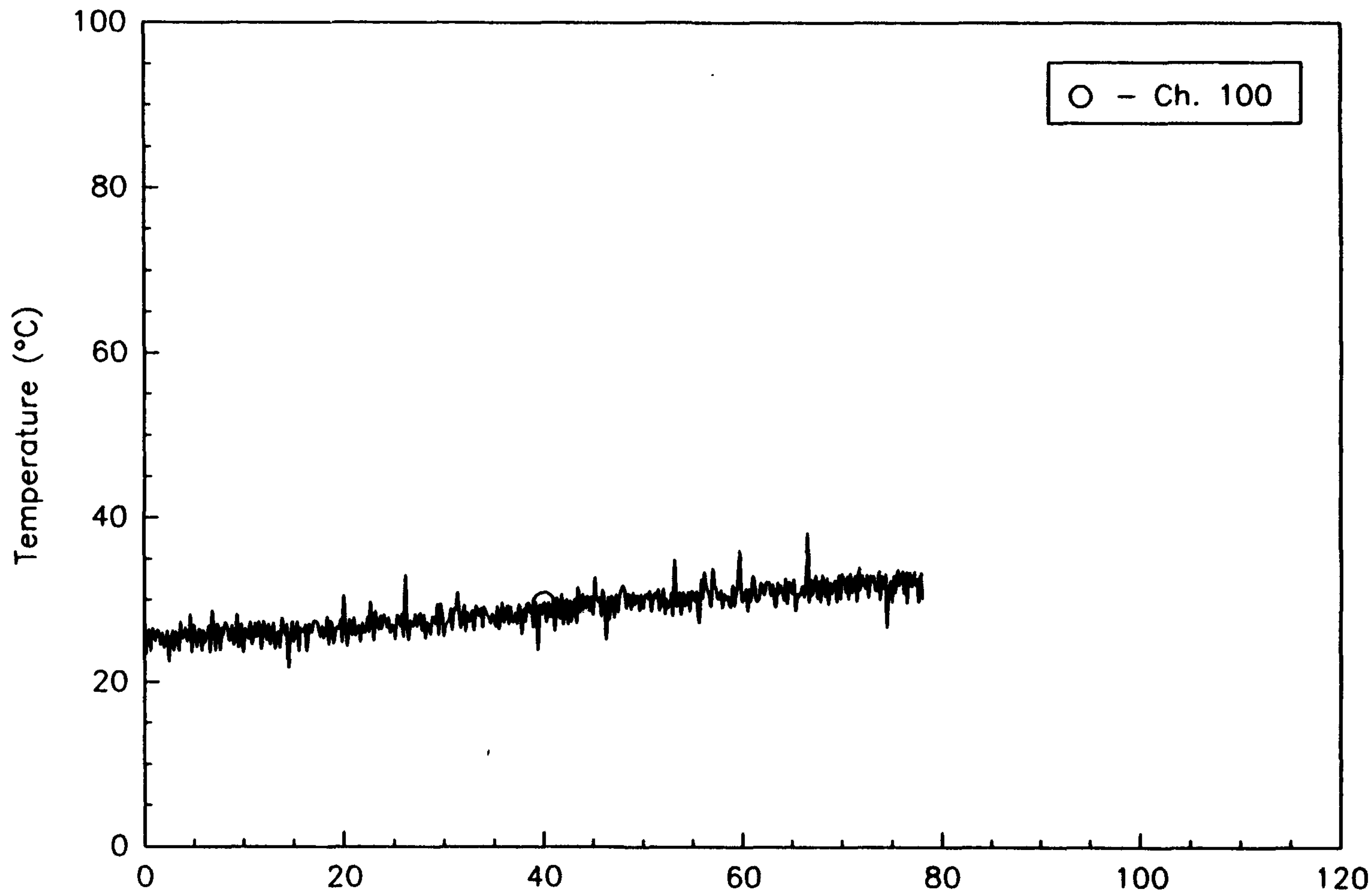

Fig. B20 – Lintel temperature at 2–26–2

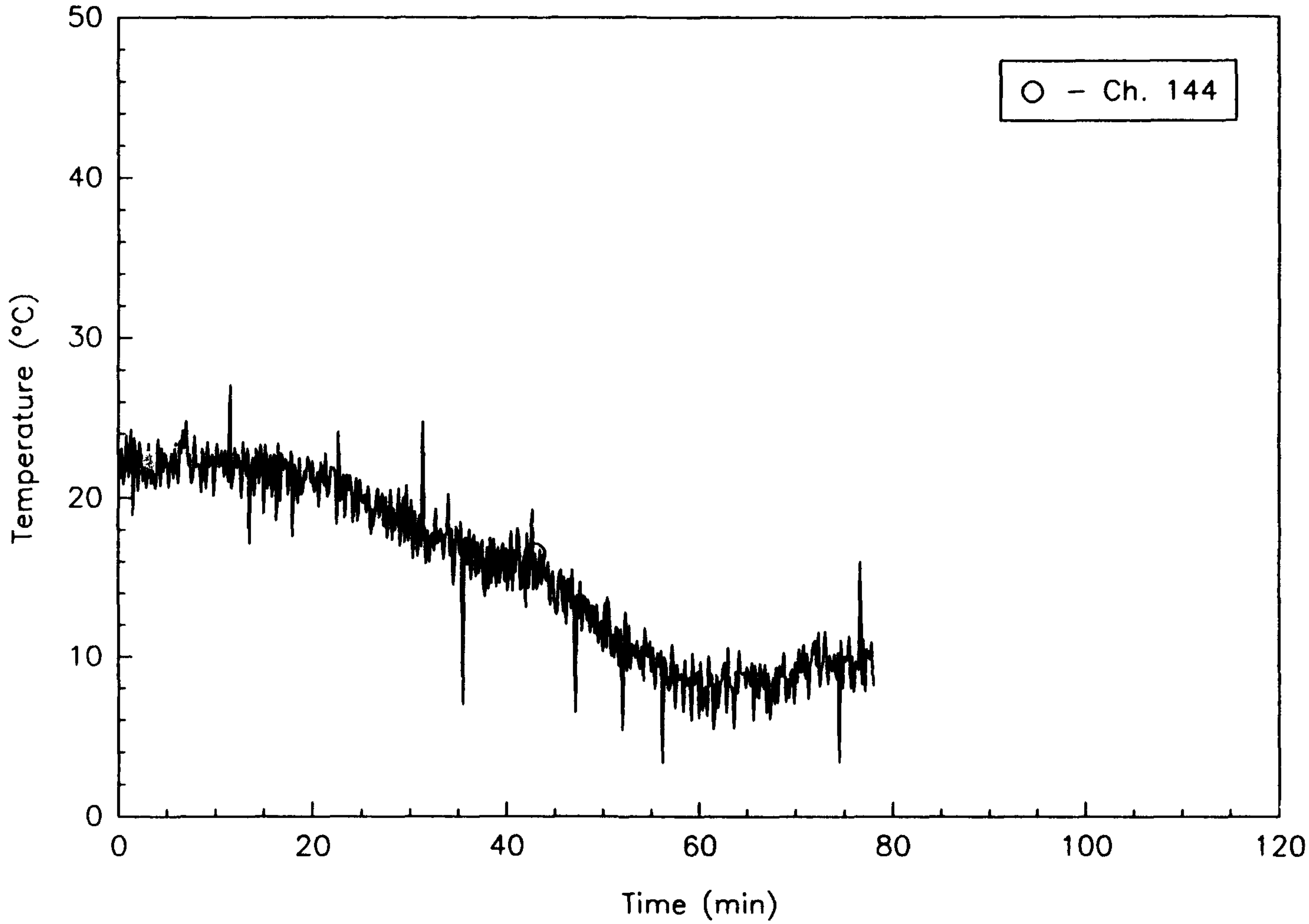

Fig. B21 – Air temperature at 2–17–2 in port passageway
152.4 cm. (60 in.) above the deck

FD_F3

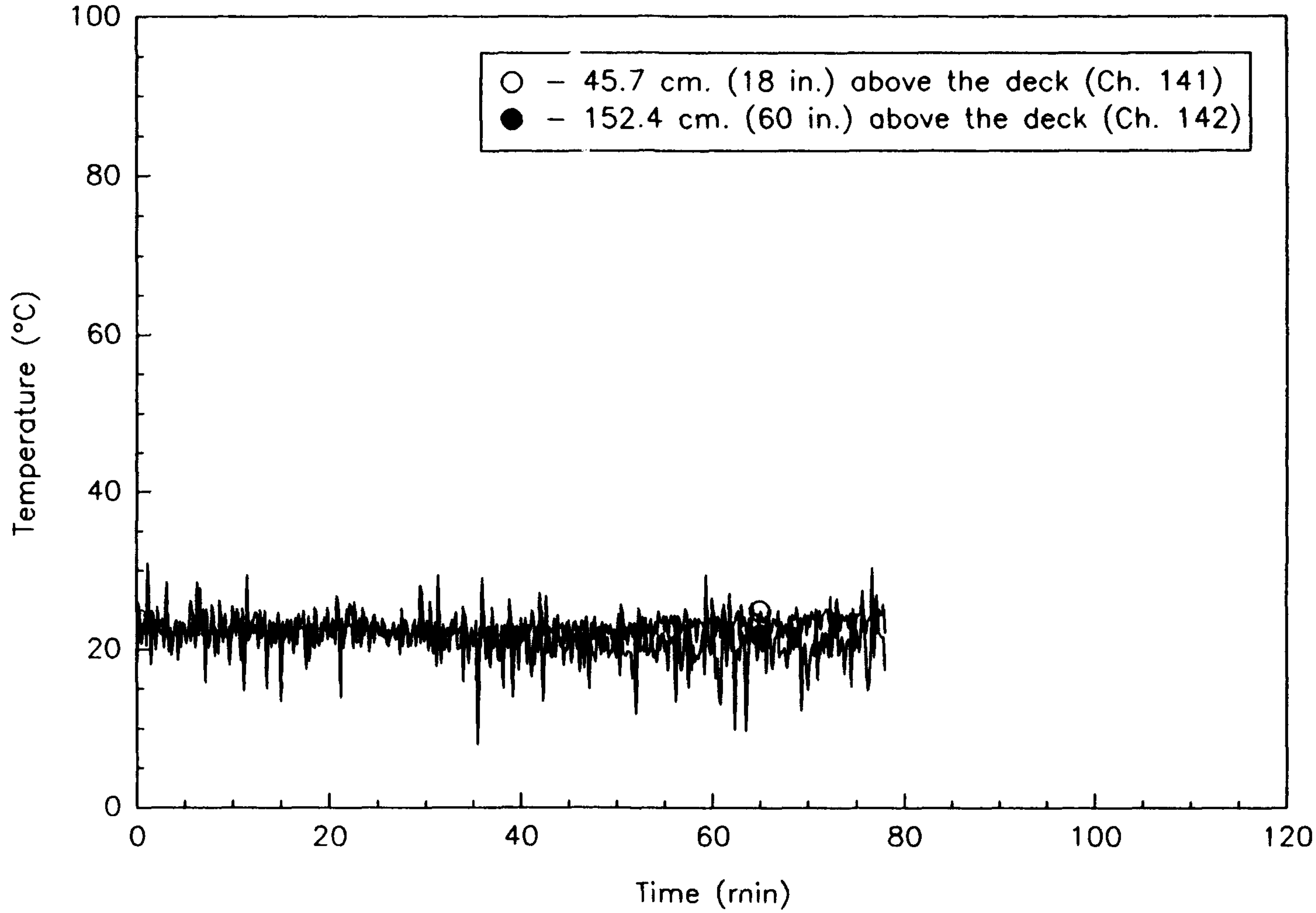

Fig. B22 – Air temperature at 2–19–2 in port passageway

FD_F3

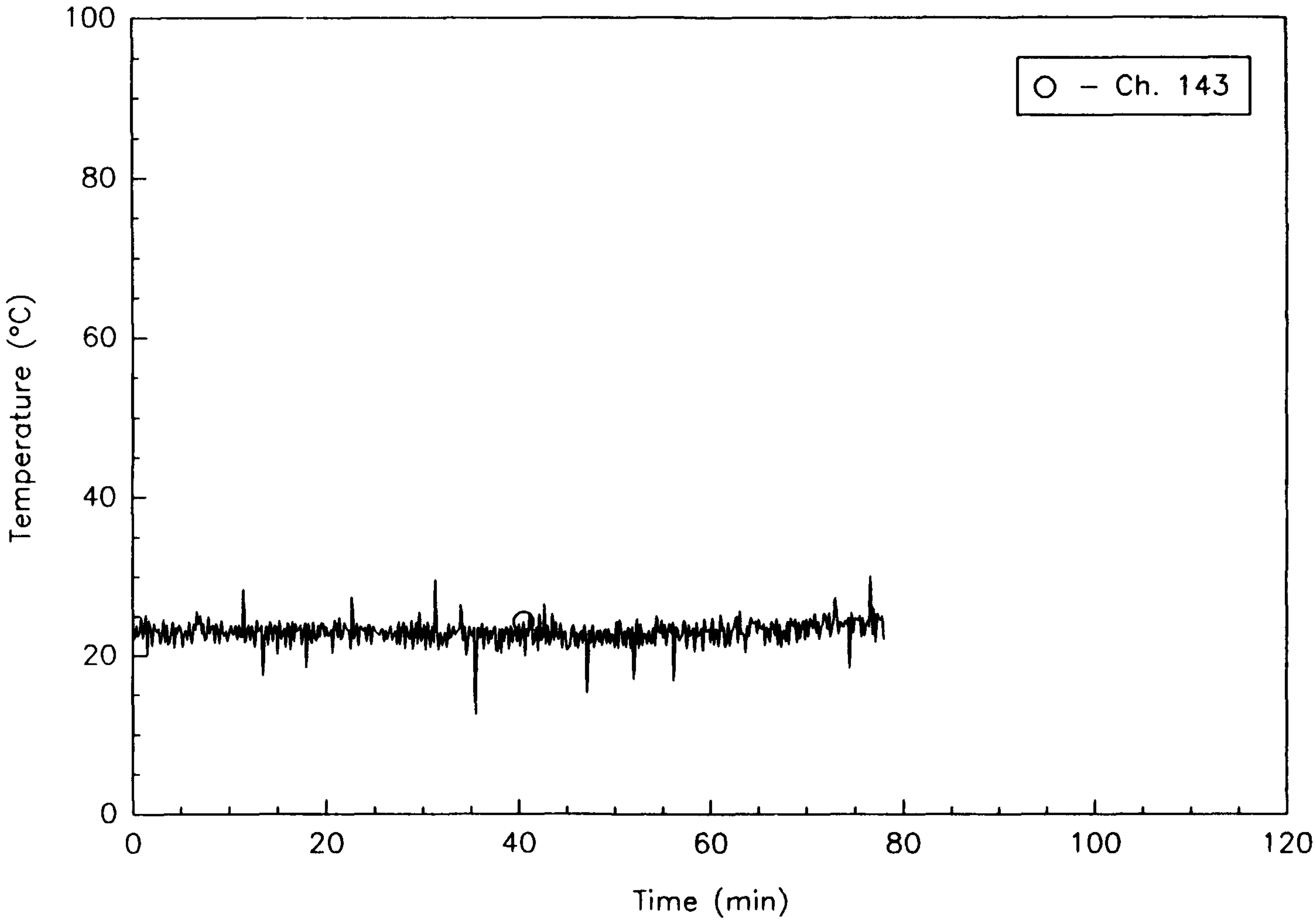

Fig. B23 – Air temperature at 2–23–2 in the port passageway
152.4 cm. (60 in.) above the deck

FD_F3

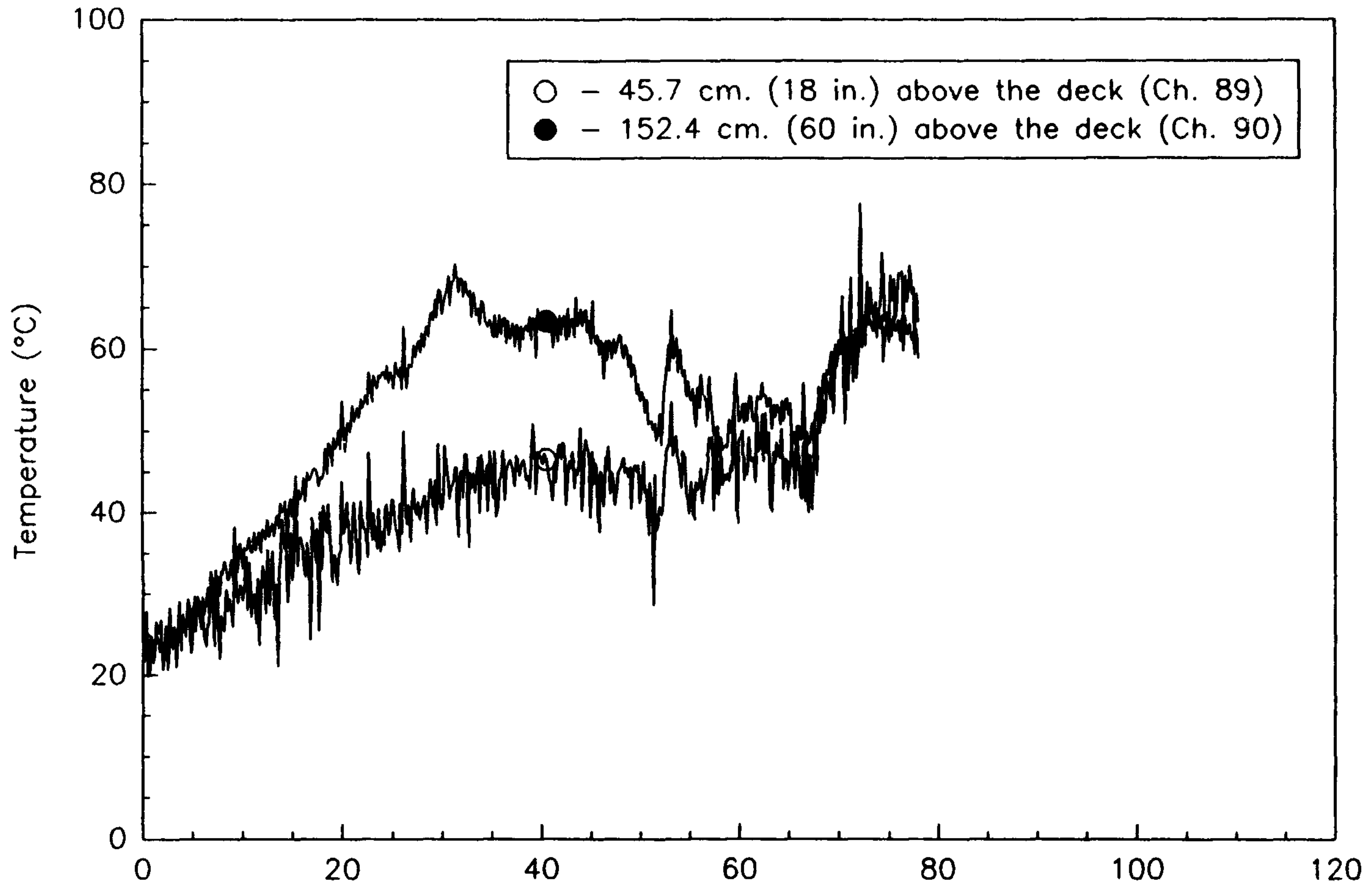

Fig. B24 – Air temperatures at 2–18–1 starboard passageway

FD_F3

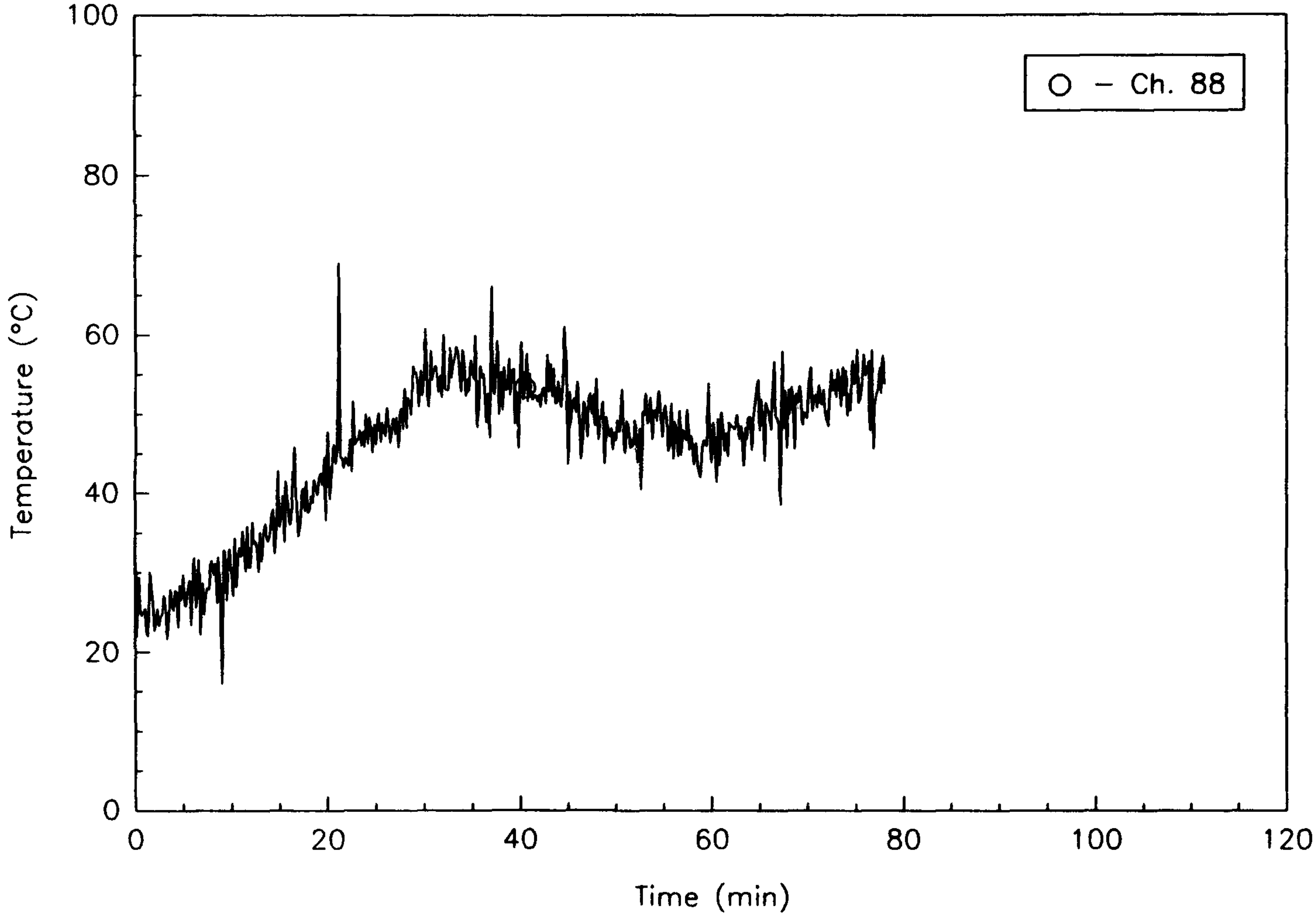

Fig. B25 – Air temperature at 2–23–1 in the starboard passageway
152.4 cm. (60 in.) above the deck

FD_F3

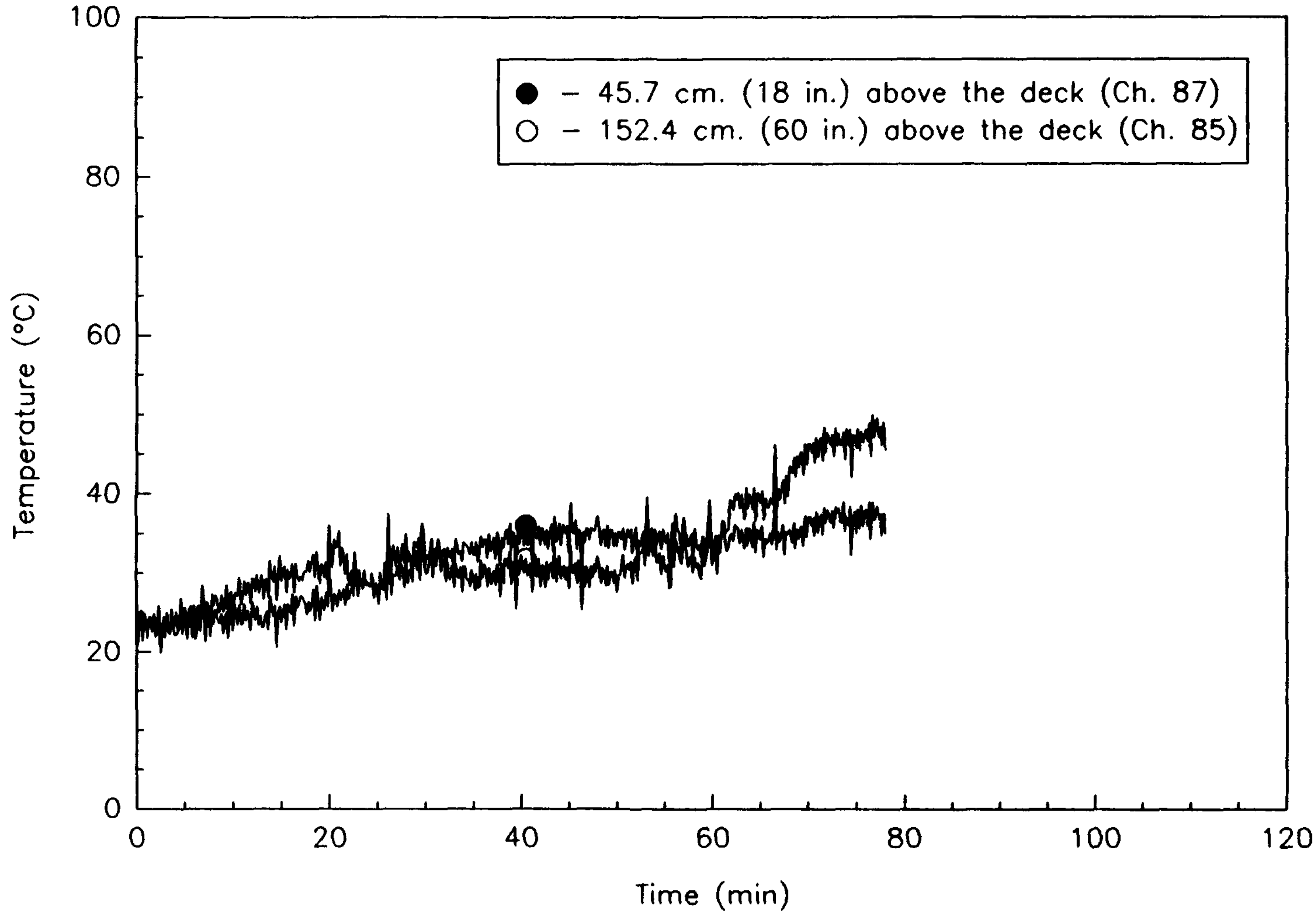

Fig. B26 – Air temperature at 2–24–1 in the starboard passageway

FD_F3

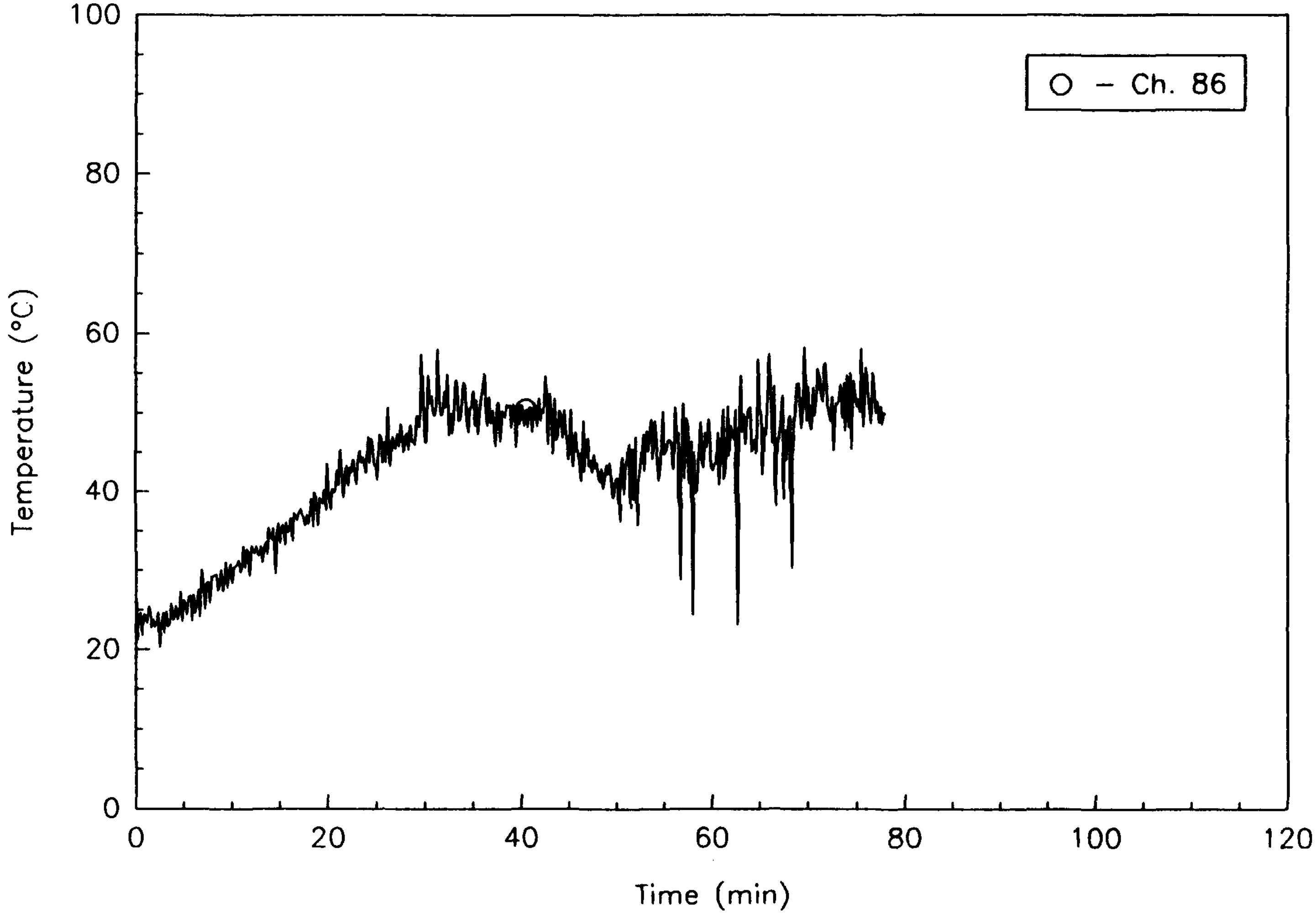

Fig. B27 – Air temperature at 2–25–1 in the starboard passageway
152.4 cm. (60 in.) above the deck

FD_F3

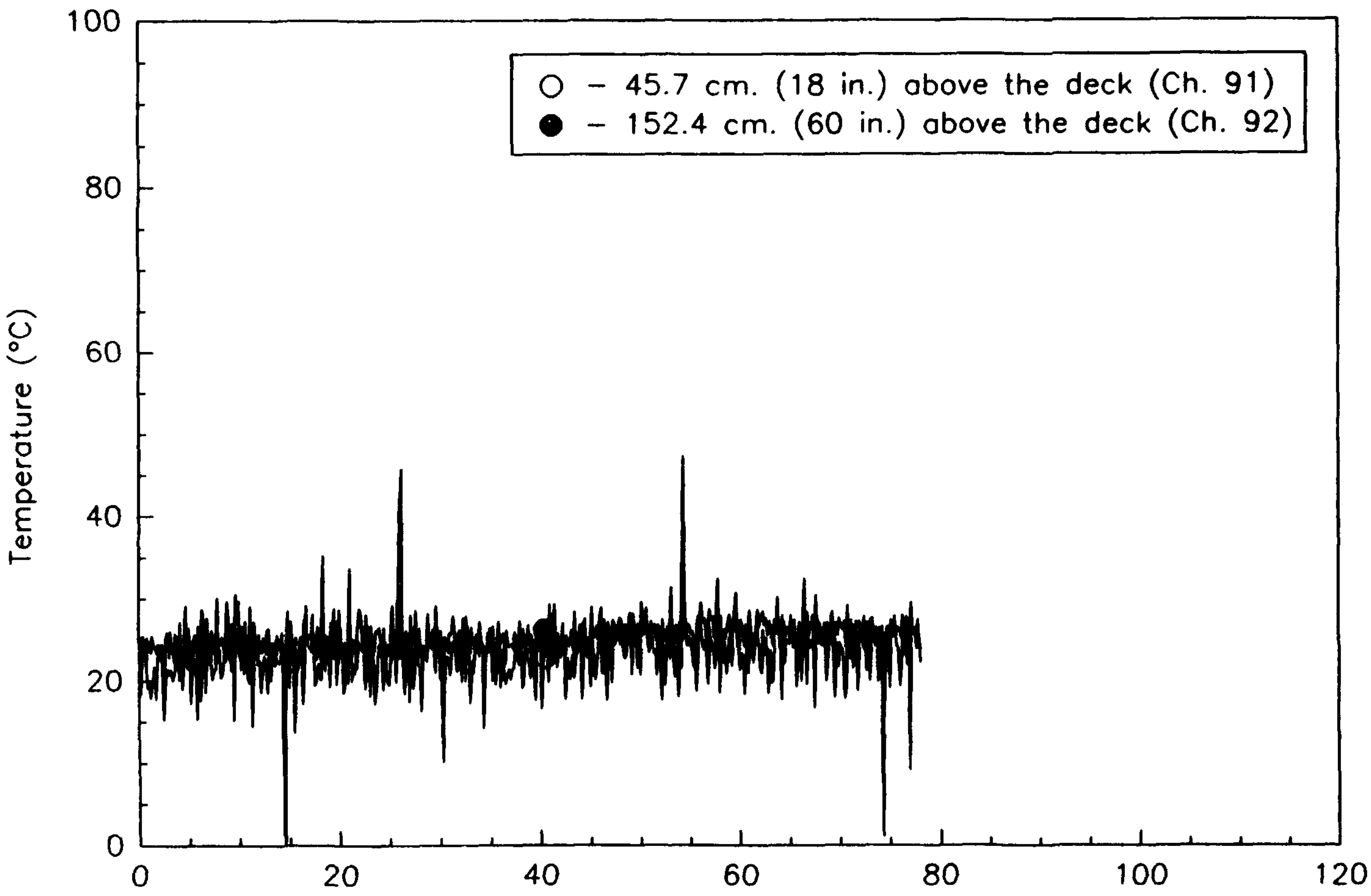

Fig. B28 – Air temperature at 2–9–1 in Repair 2

FD_F3

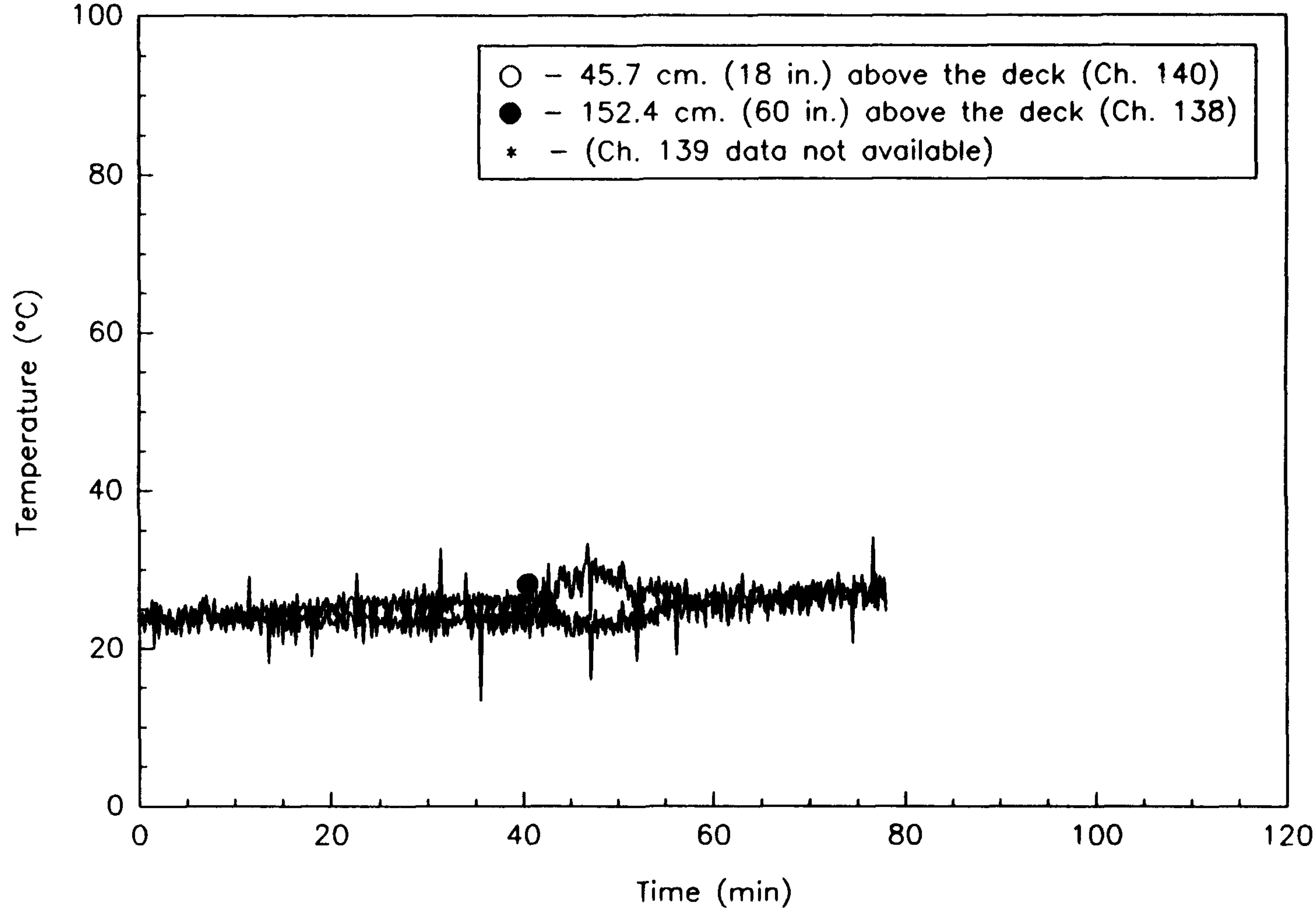

Fig. B29 – Air temperature at 2–13–2 athwartship passageway

FD_F3

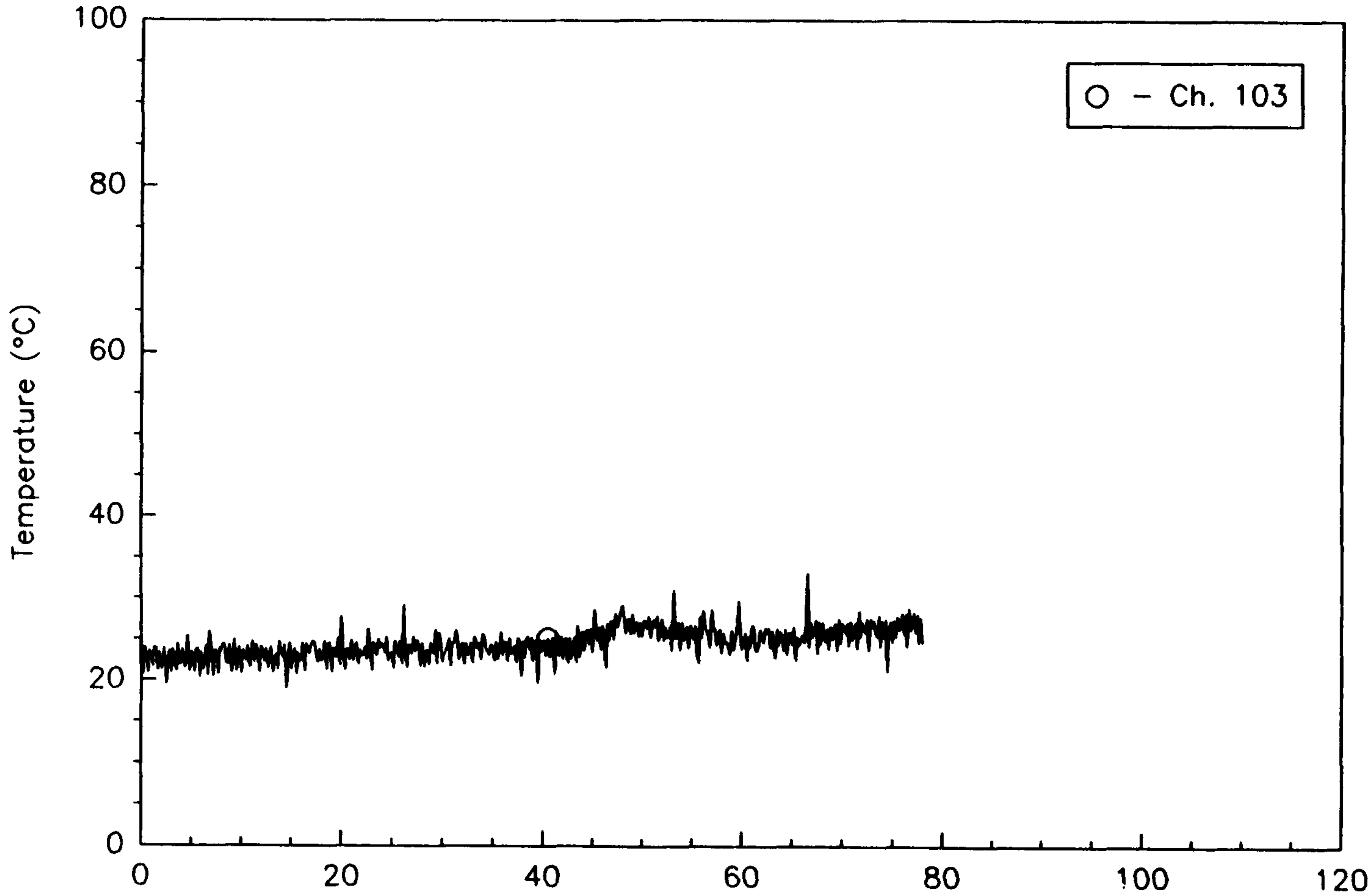

Fig. B30 – Bulkhead temperature at 2–14–2 in the port passageway 152.4 cm. (60 in.) above the deck

FD_F3

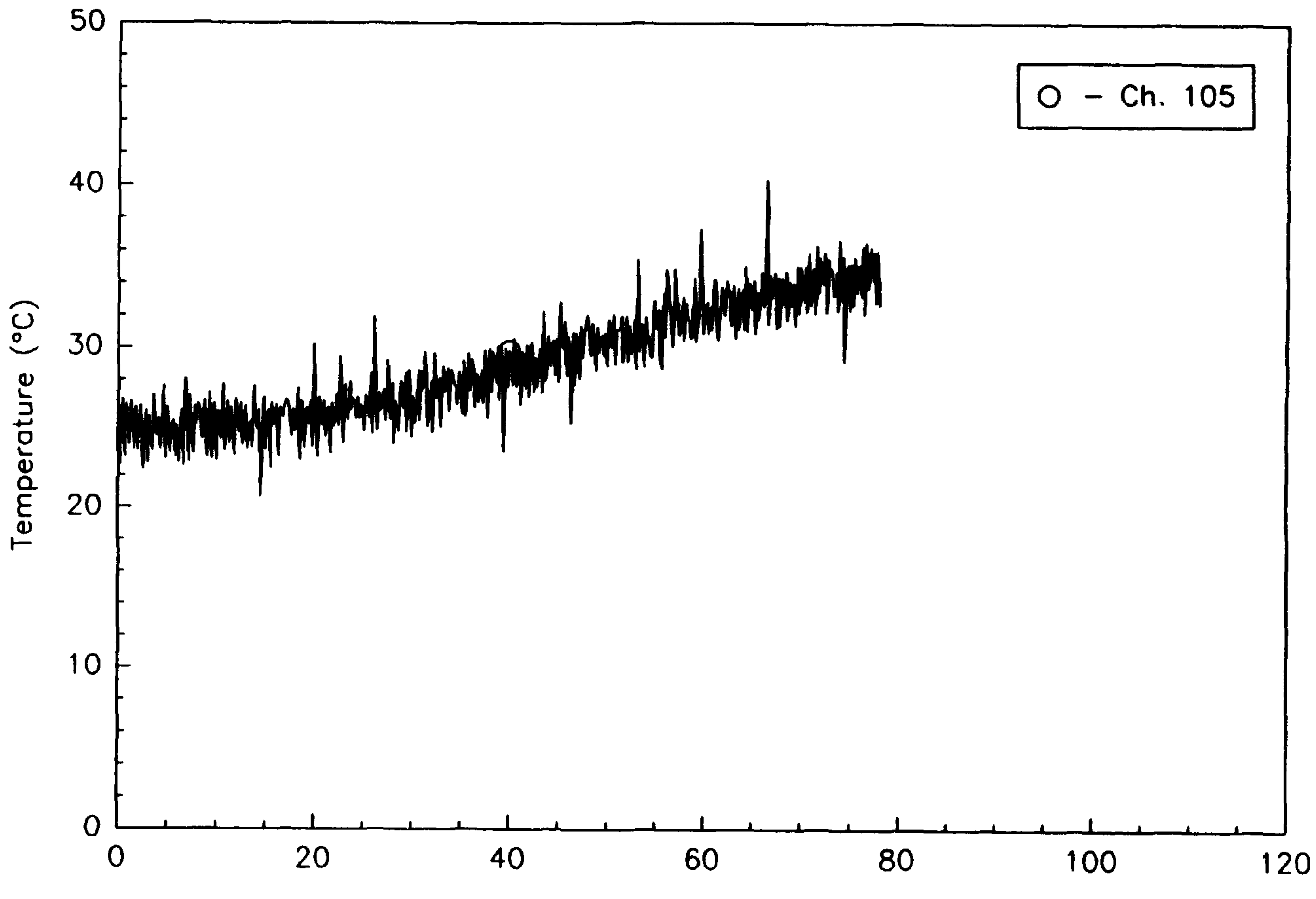

Fig. B31 - Bulkhead temperature at 2-22-2 in the port passageway 152.4 cm. (60 in.) above the deck

FD_F3

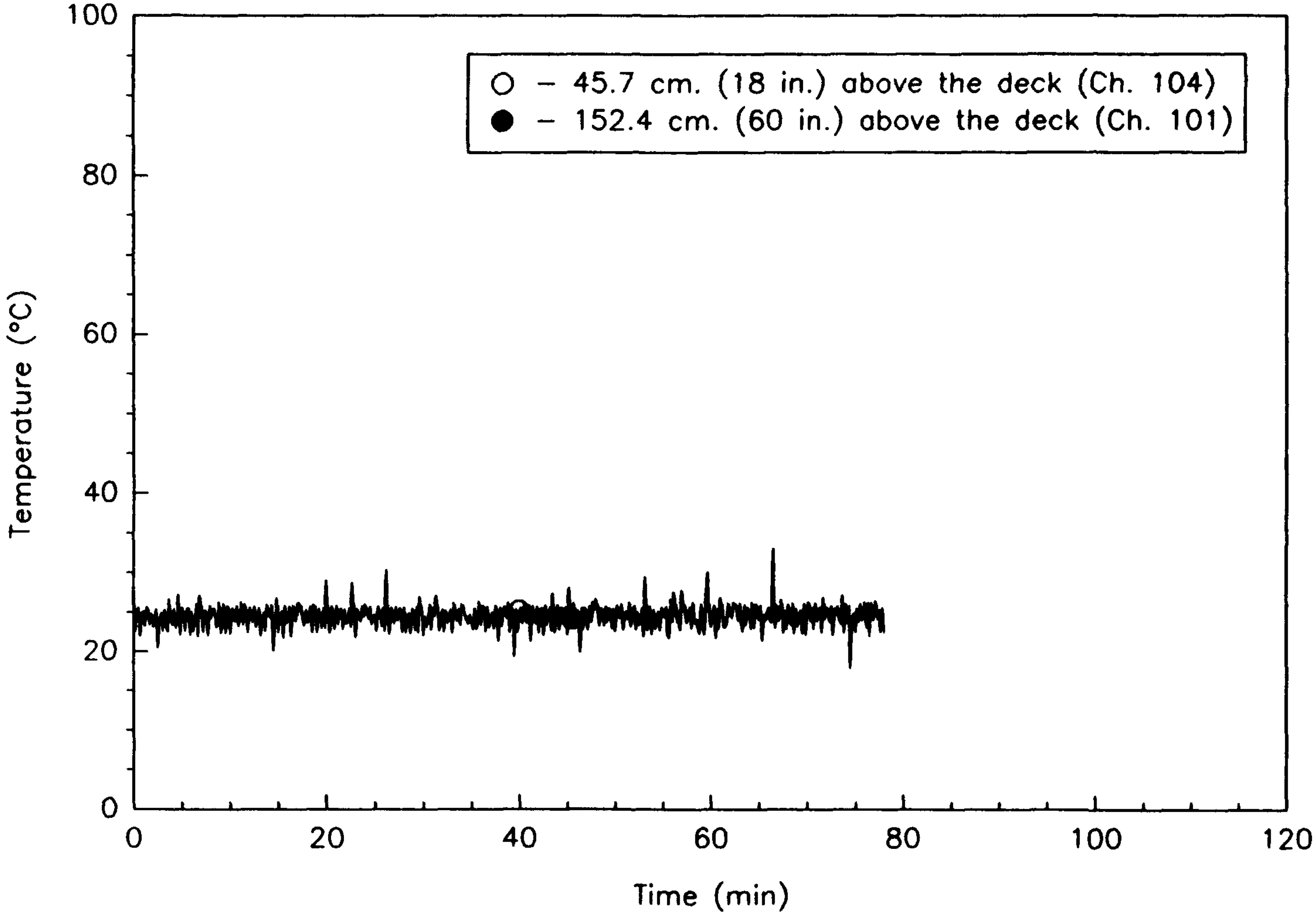

Fig. B32 – Bulkhead temperature at 2–23–2 in the port passageway

FD_F3

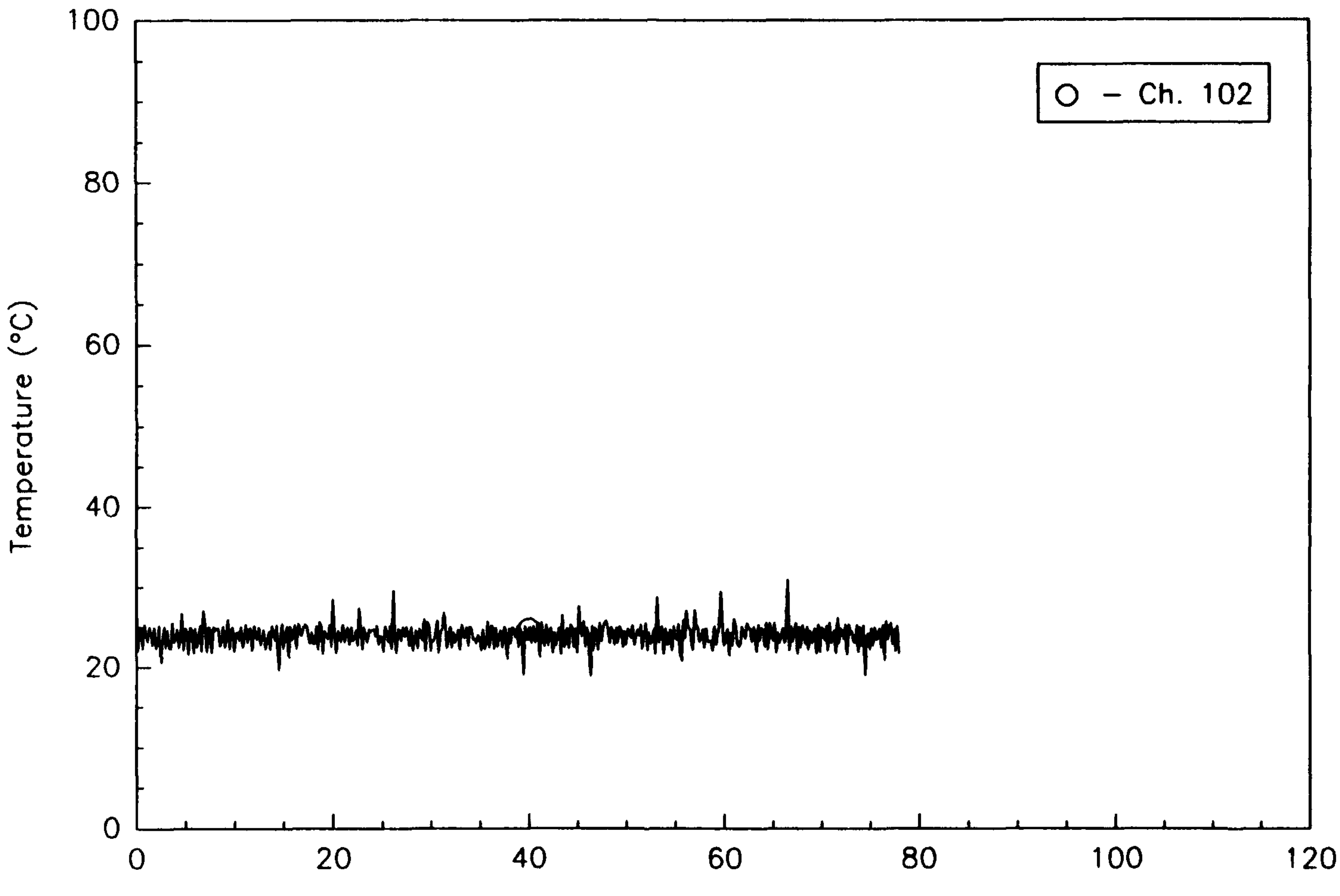

Fig. B33 – Bulkhead temperature at 2–26–2 152.4 cm. (60 in.) above the deck

FD_F3

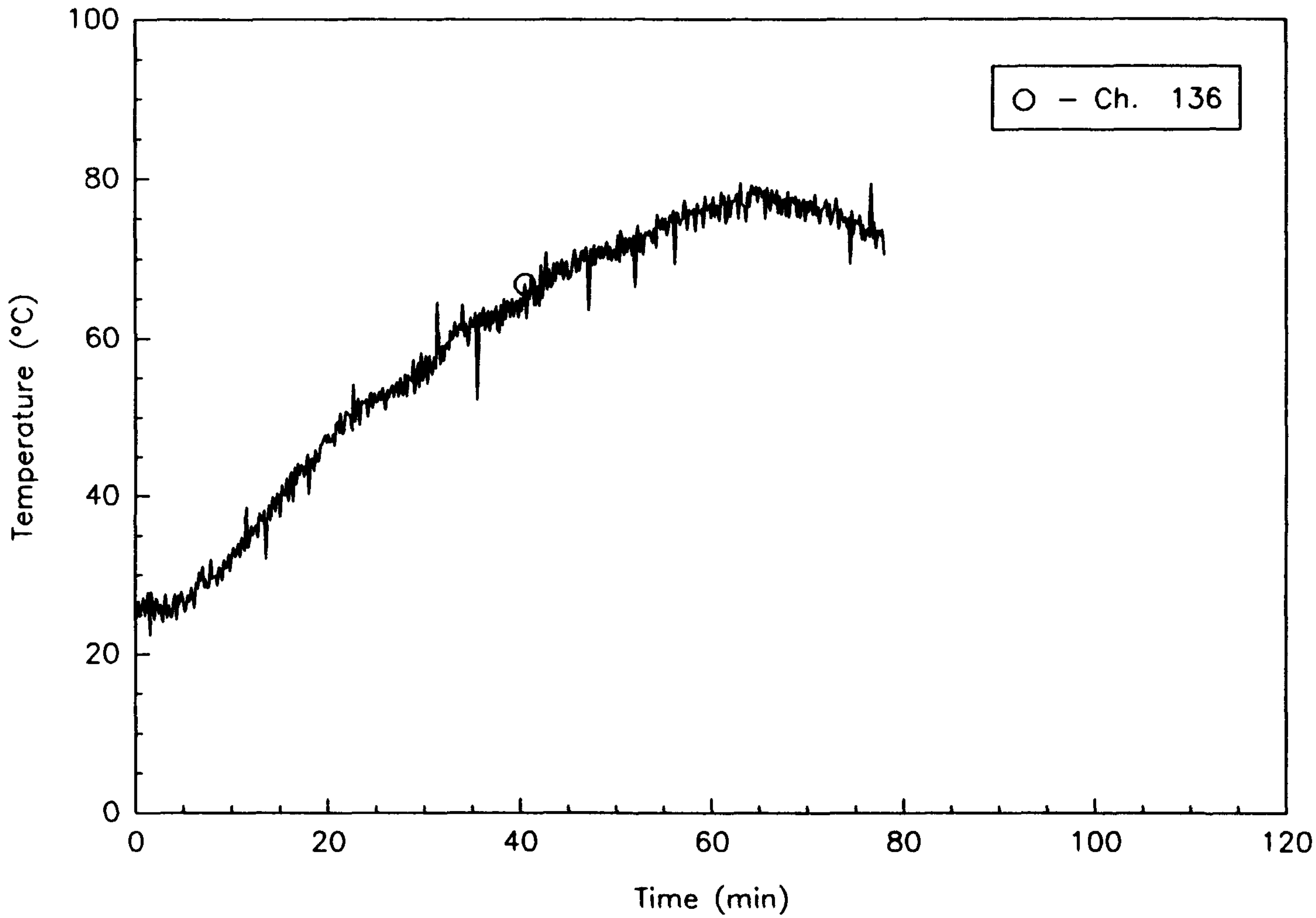

Fig. B34 – Air temperature at 1–17–0 30.5 cm. (12 in.) below overhead

FD_F3

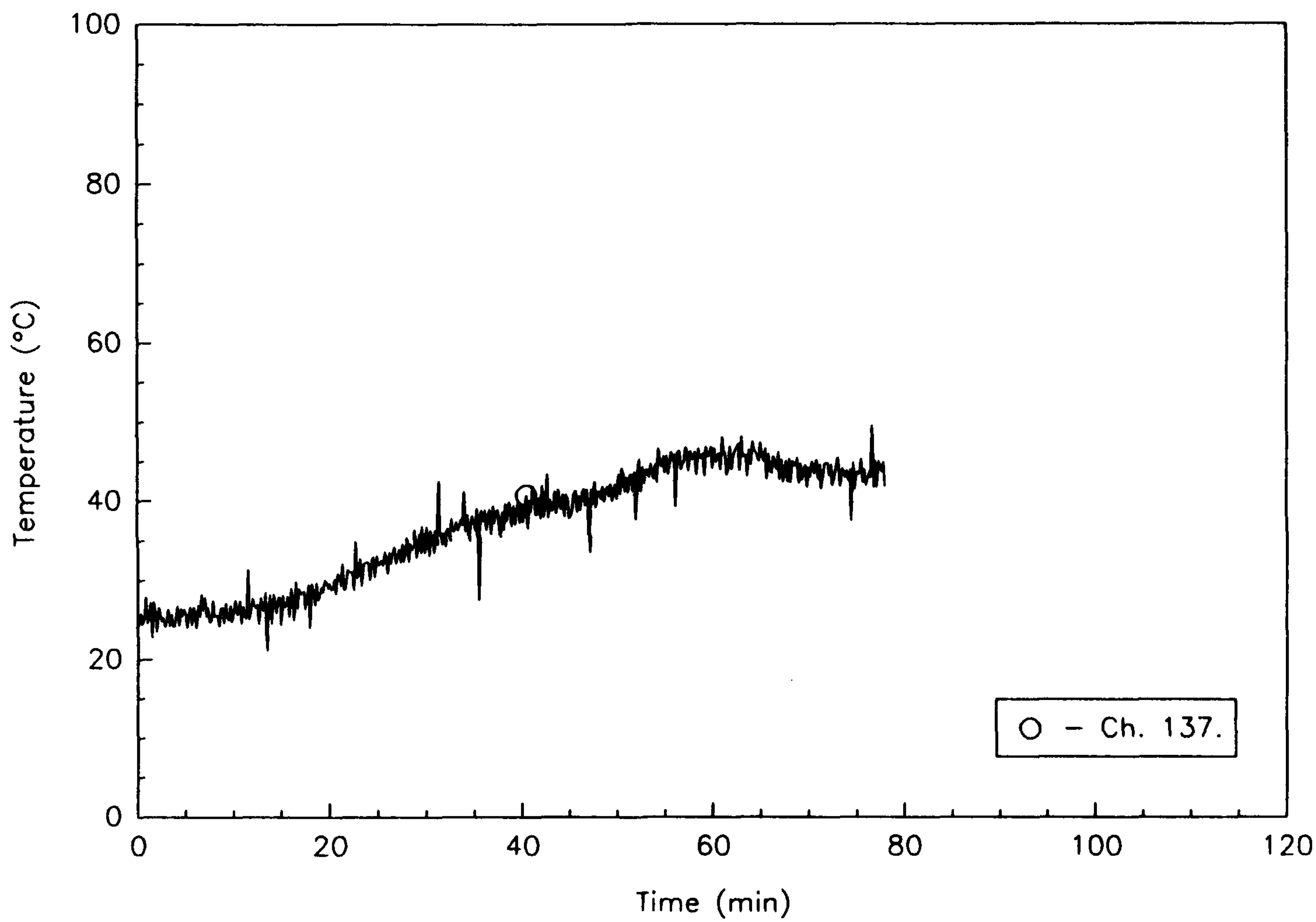

Fig. B35 – Air temperature at 1–21–0 152.4 cm. (60 in.) above the deck

FD_F3

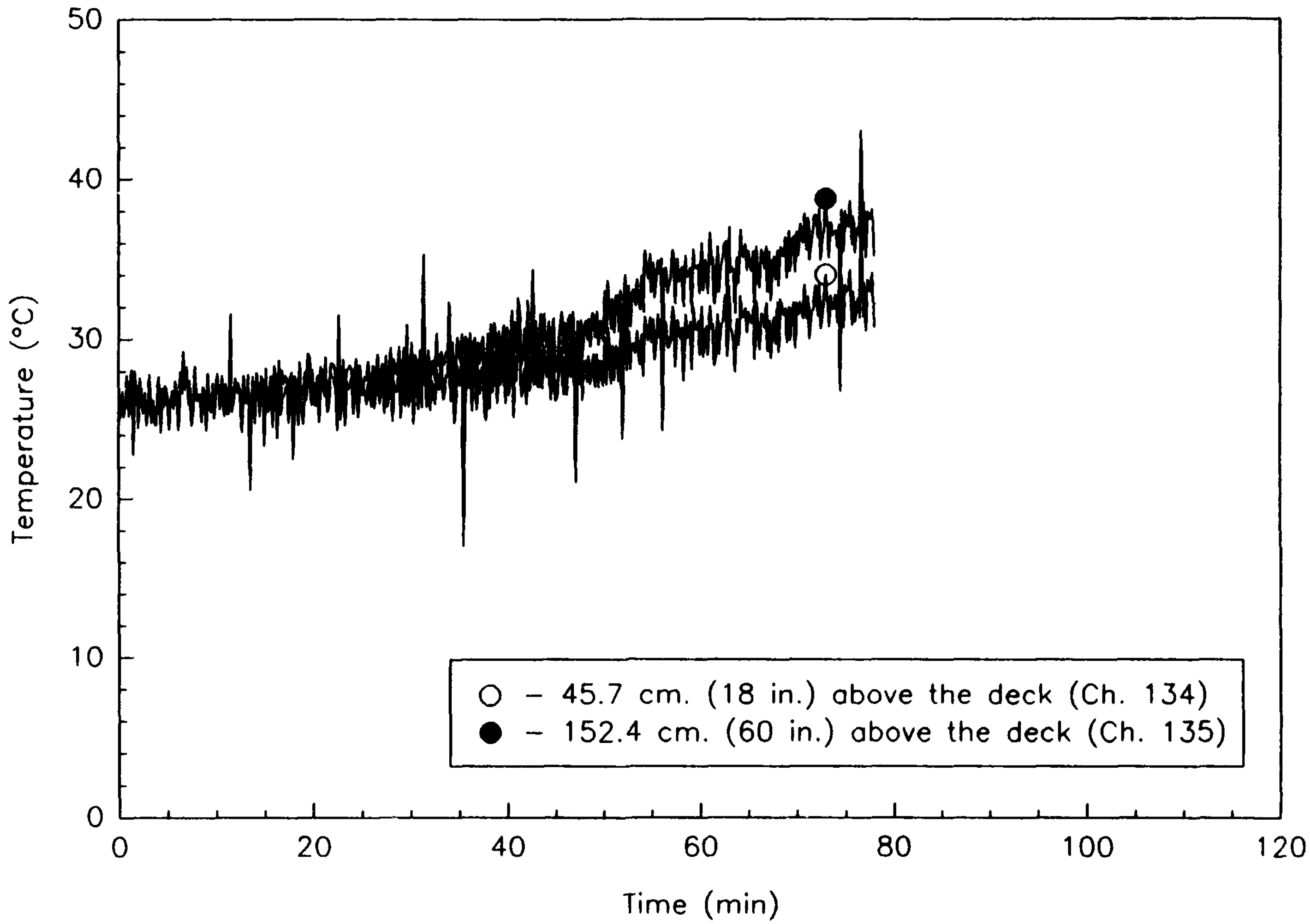

Fig. B36 – Air temperature at 1-26-0

FD_F3

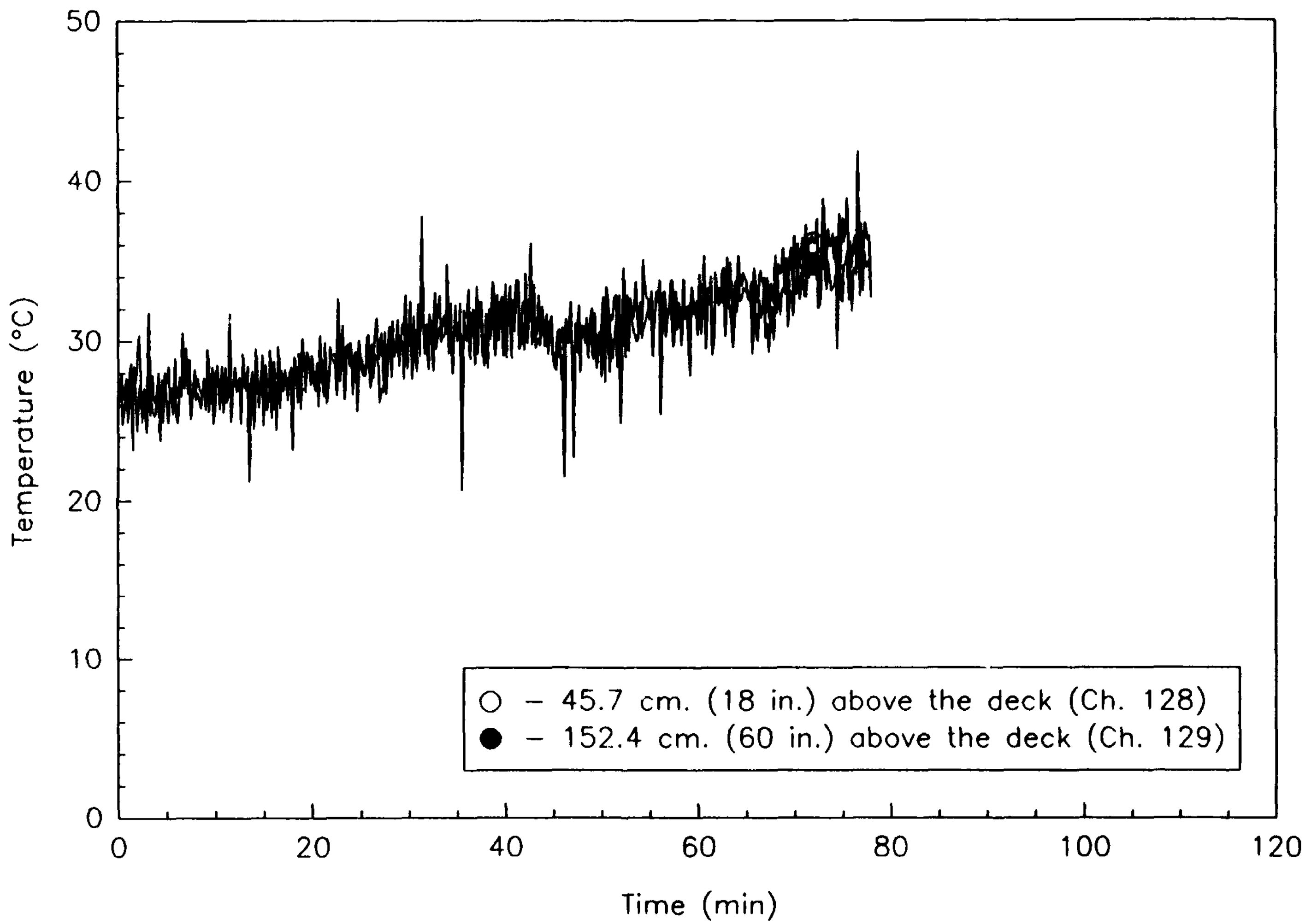

Fig. B37 – Air temperature at 1–23–1 in starboard passageway

FD_F3

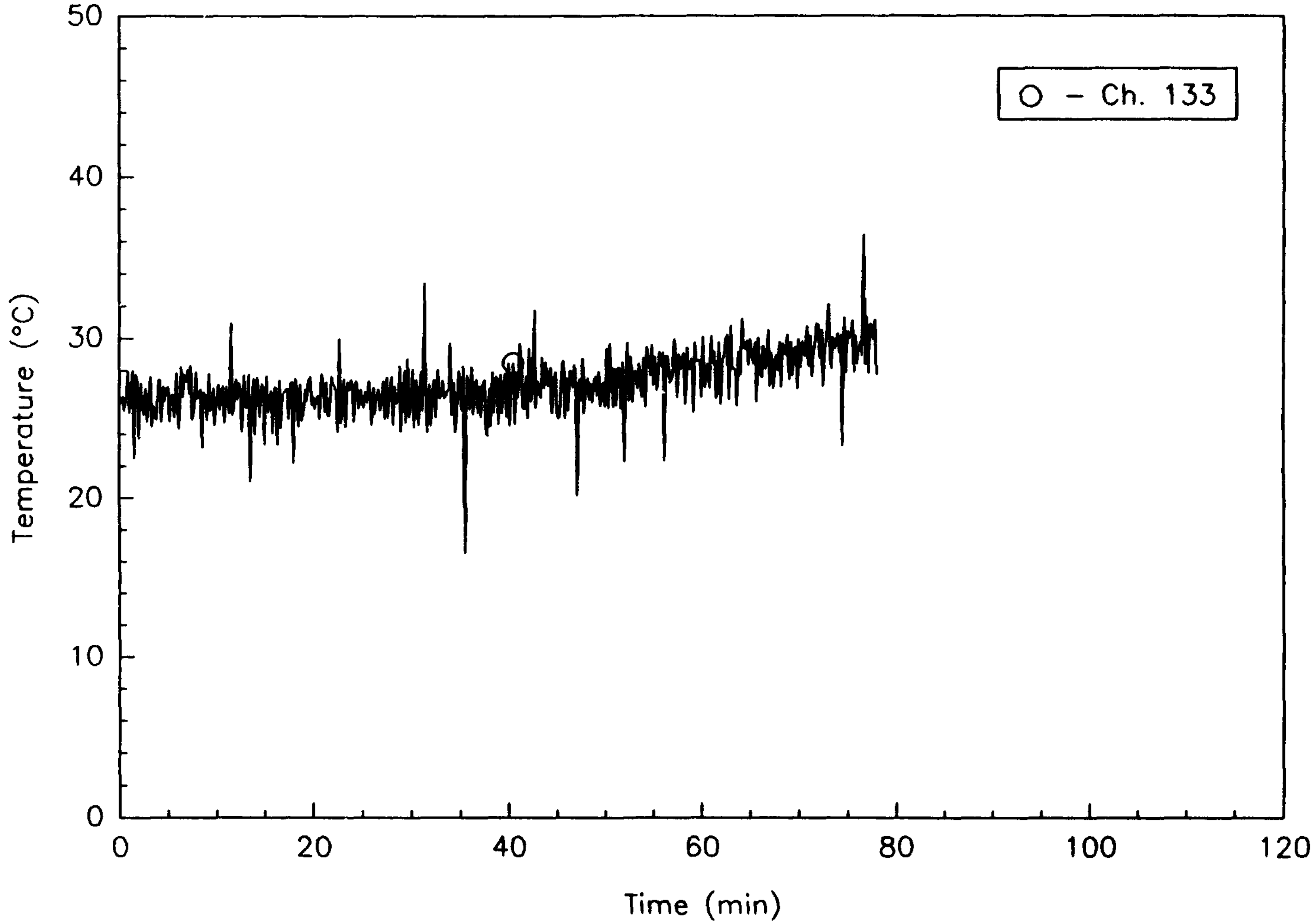

Fig. B38 – Deck temperature at 1–26–0

FD_F3

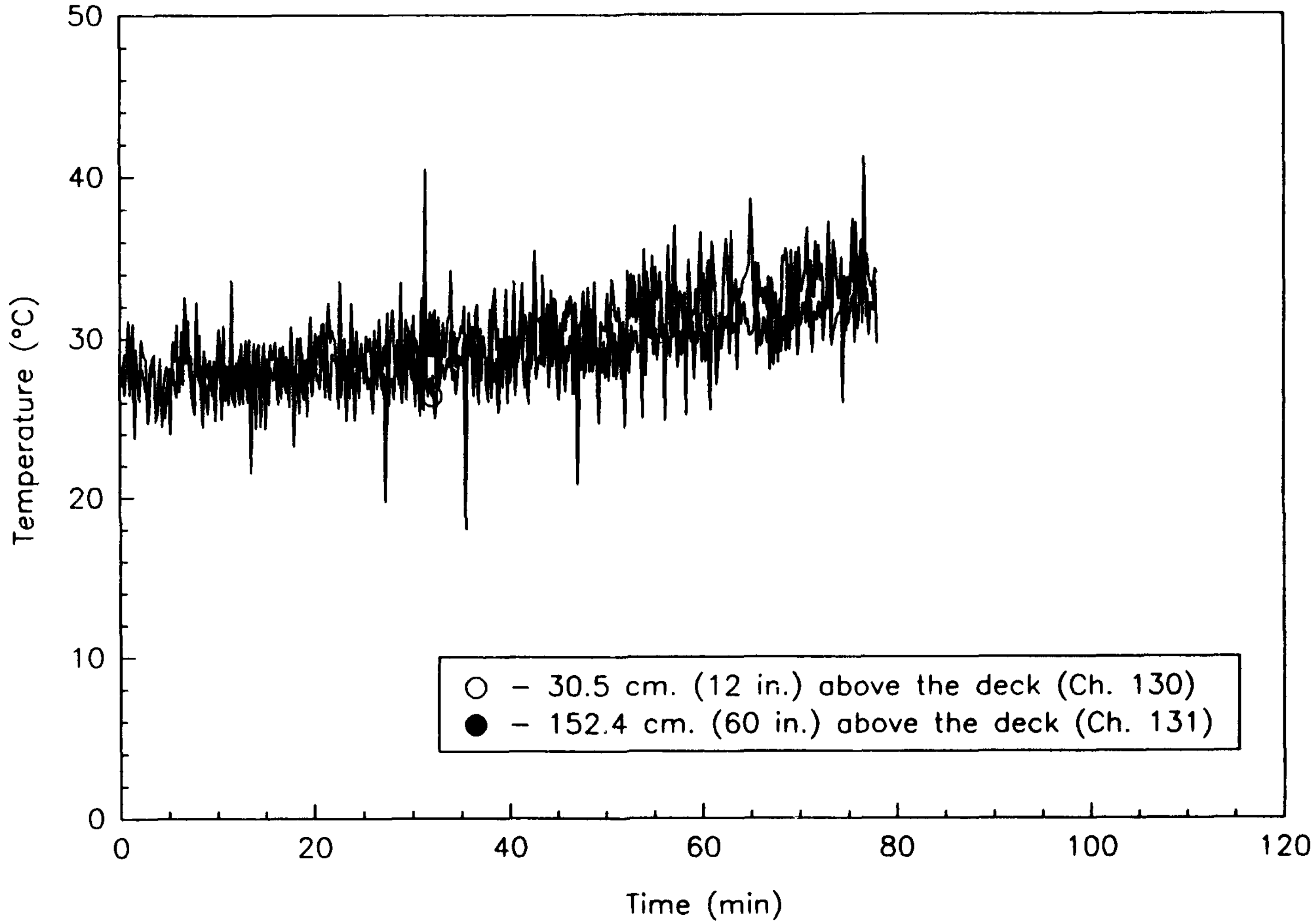

Fig. B39 – Bulkhead temperature at 1–24–1 in the Emergency Diesel Generator Room

FD_F3

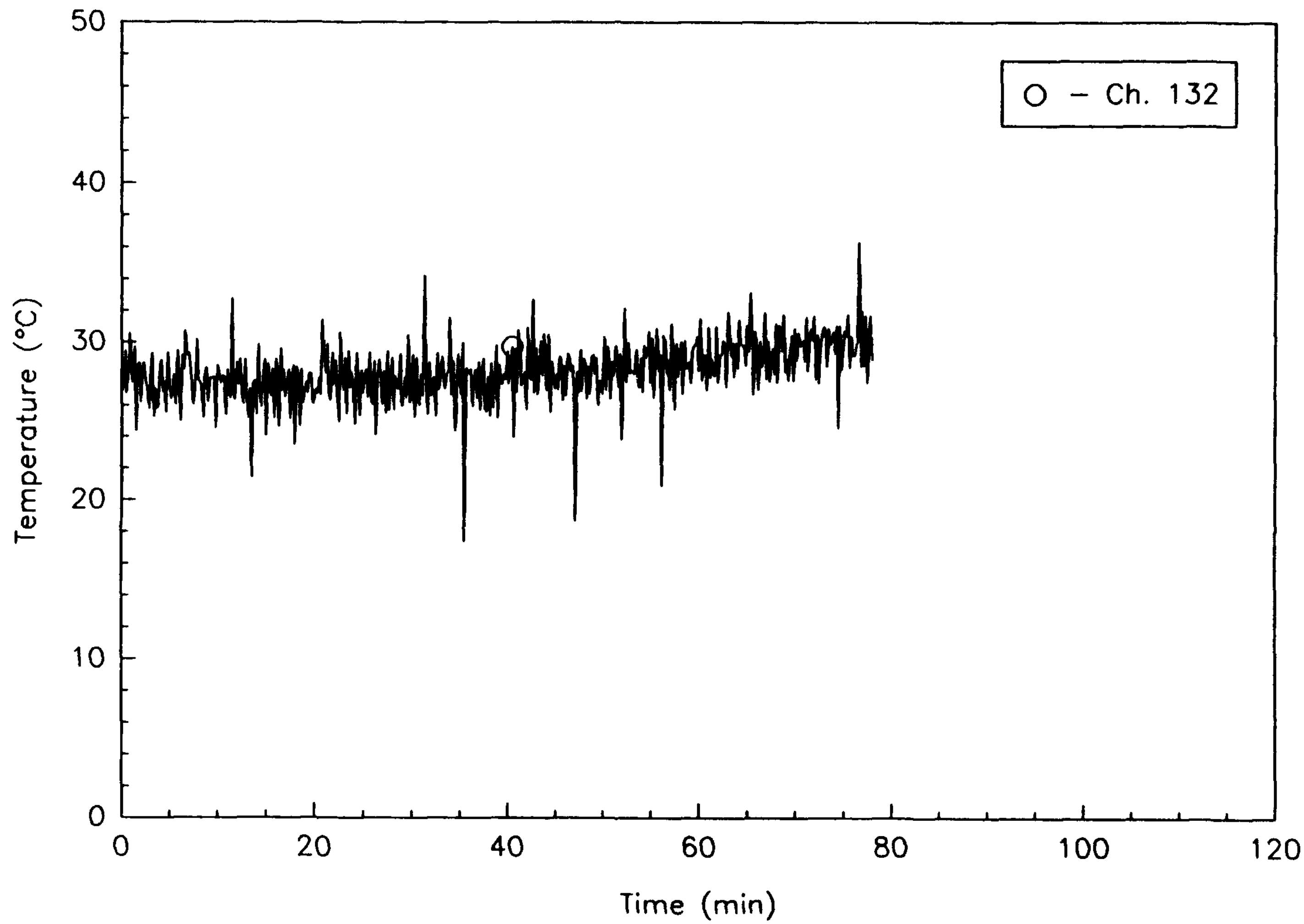

Fig. B40 – Deck temperature at 1–25–1 in the Emergency Diesel Generator Room

FD_F3

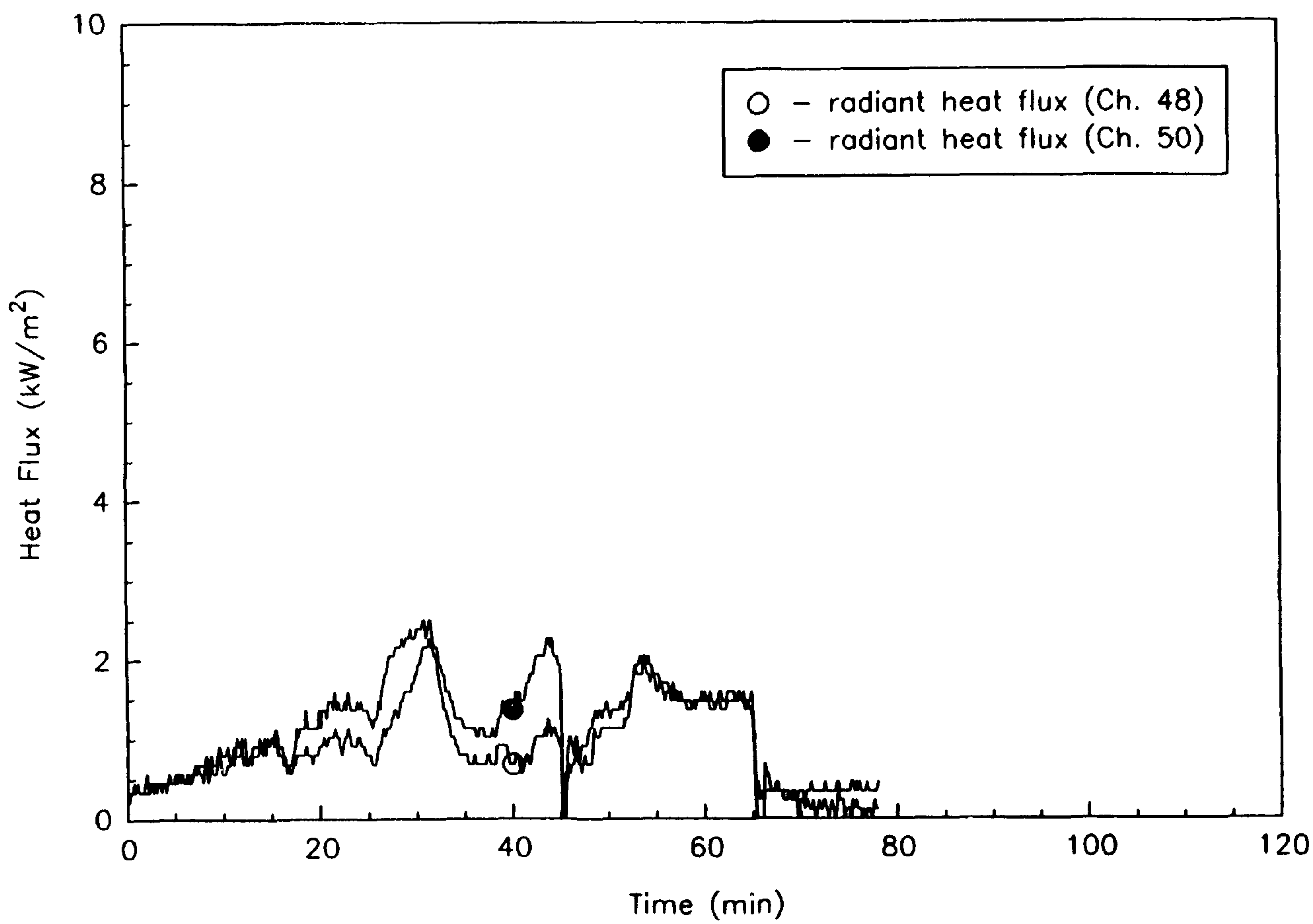

Fig. B41 – Heat flux at 3–20–1 viewing crib # 1

FD_F3

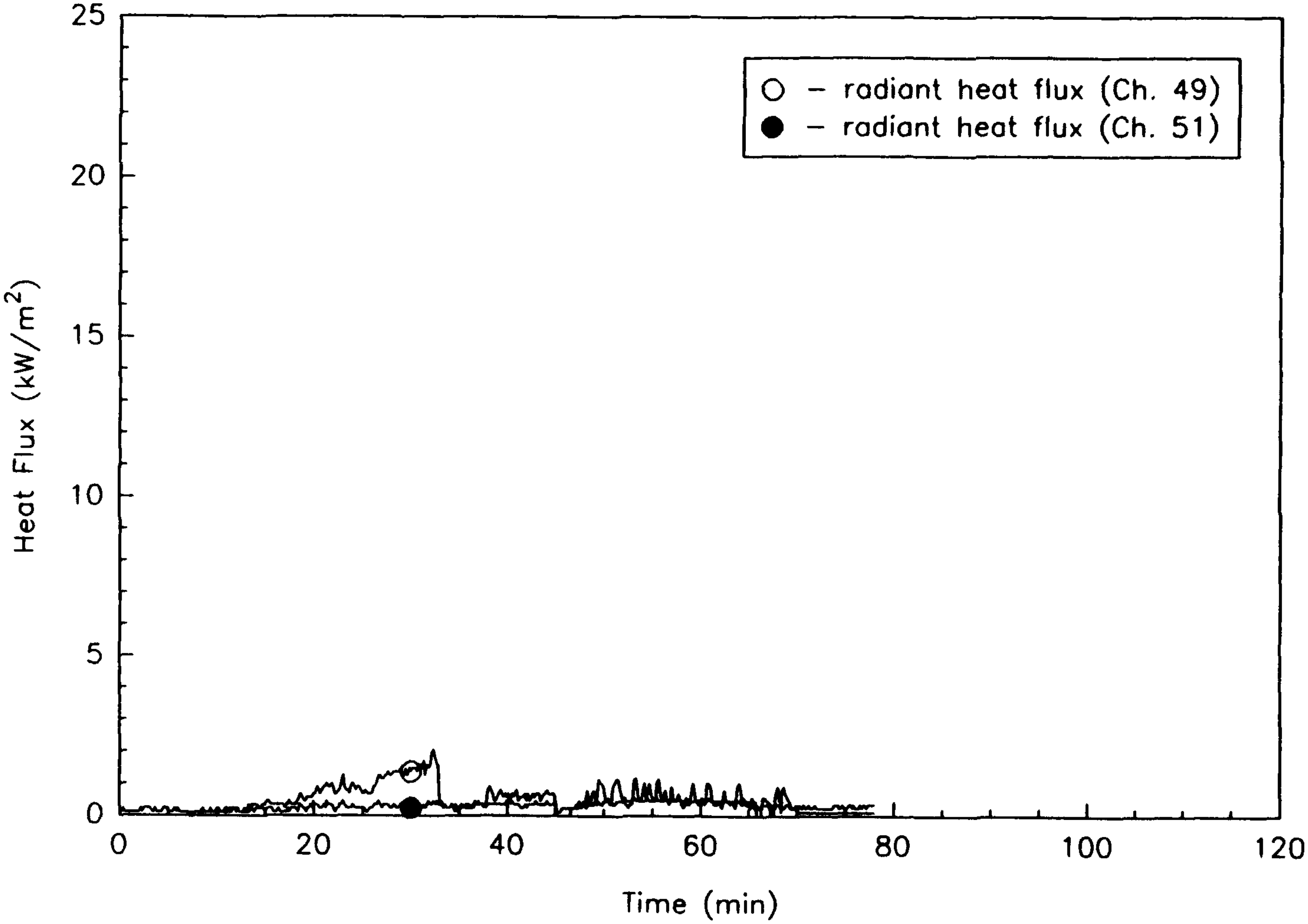

Fig. B42 – Heat flux at 3–20–0 (top of hatch)

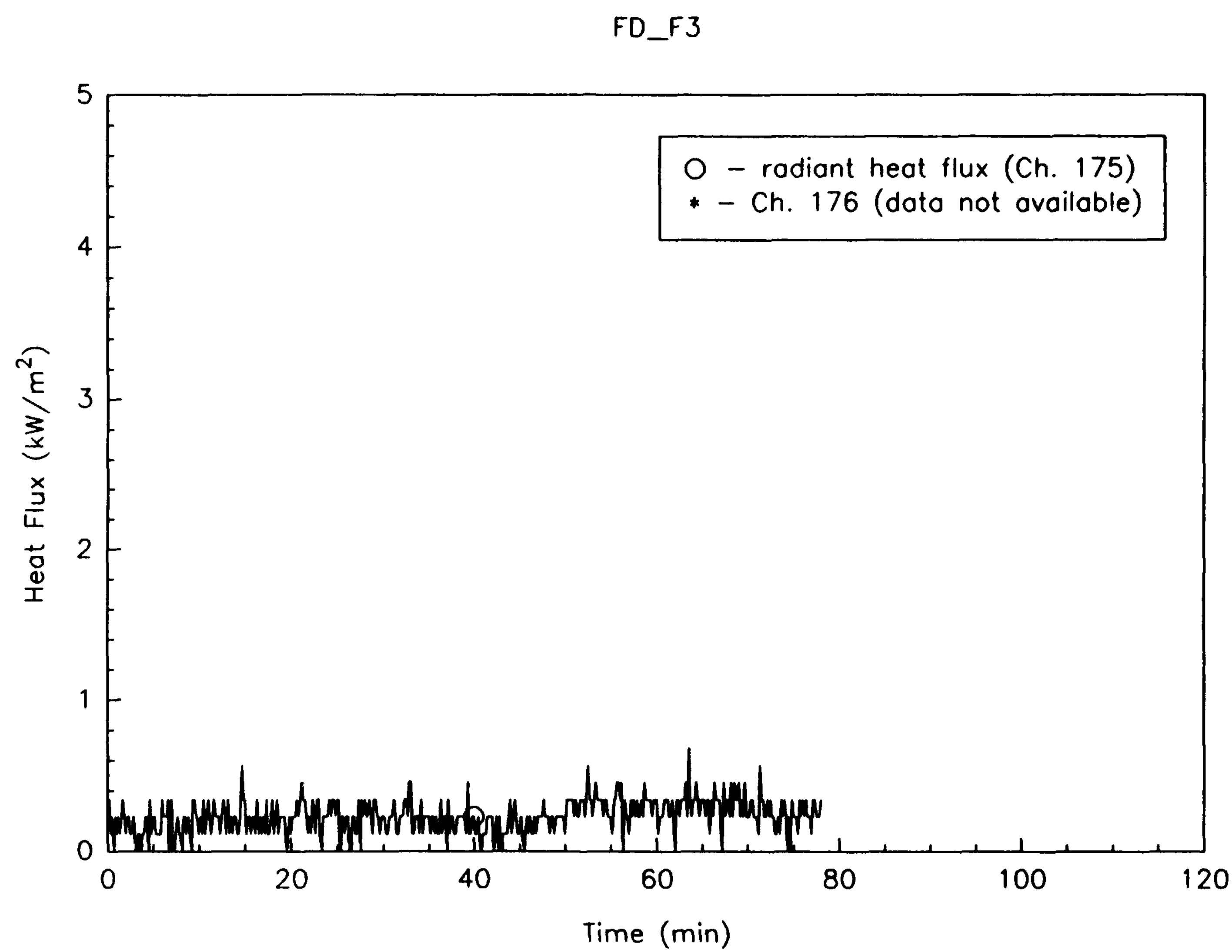

Fig. B43 – Heat flux at 2-21-0 viewing hatch

FD_F3

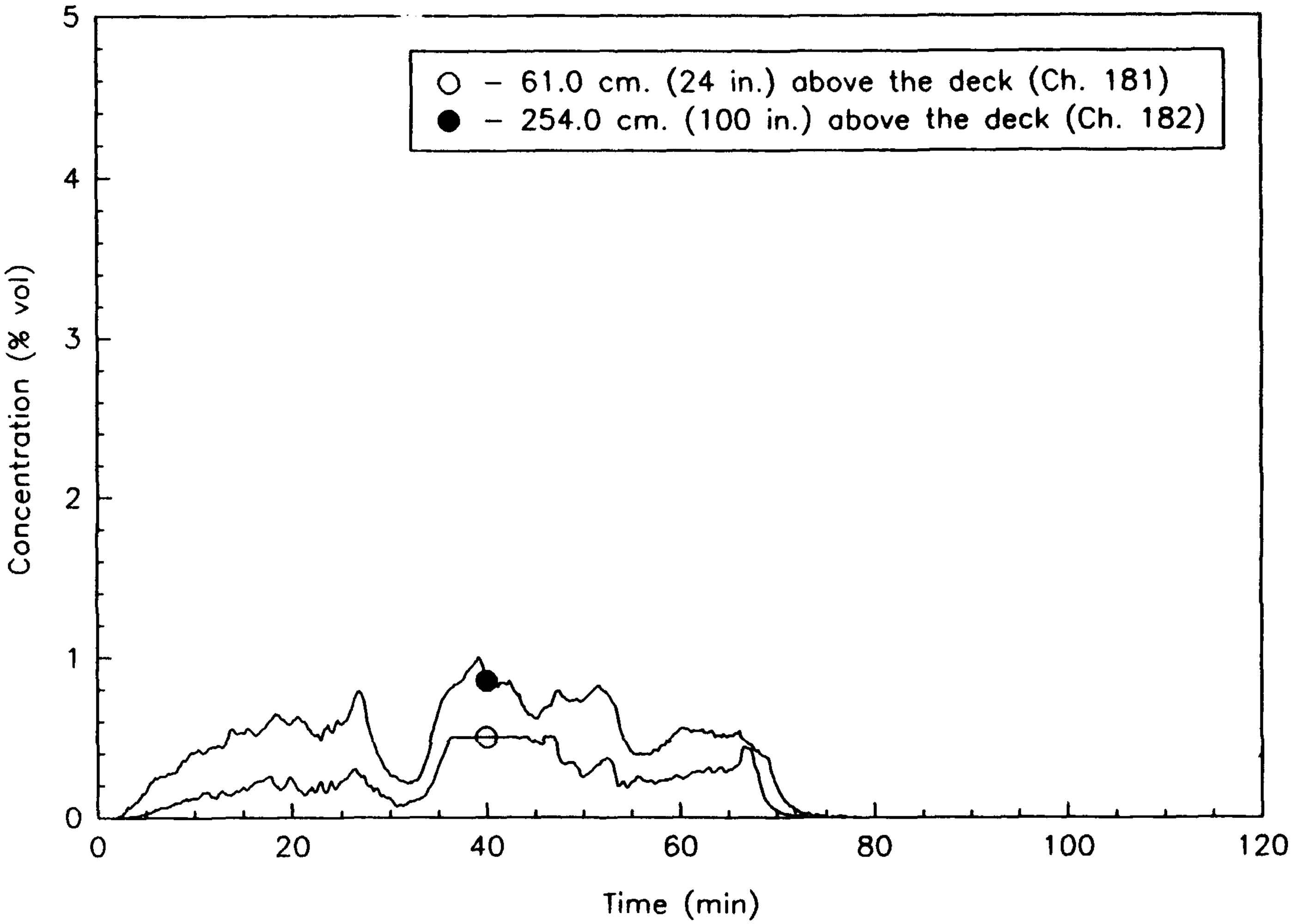

Fig. B44 – Carbon monoxide concentrations at 3-20-2

FD_F3

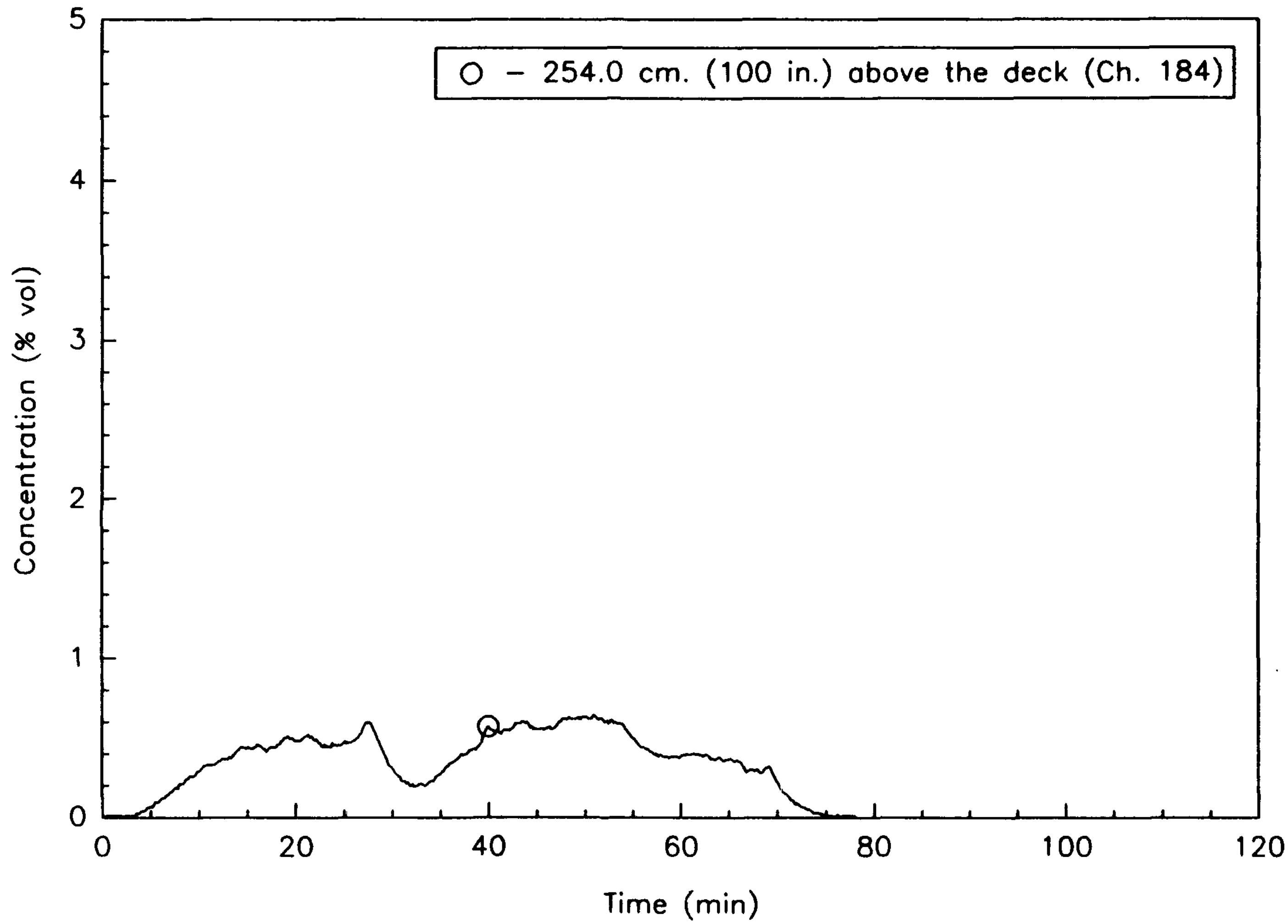

Fig. B45 – Carbon monoxide concentration at 2-17-2

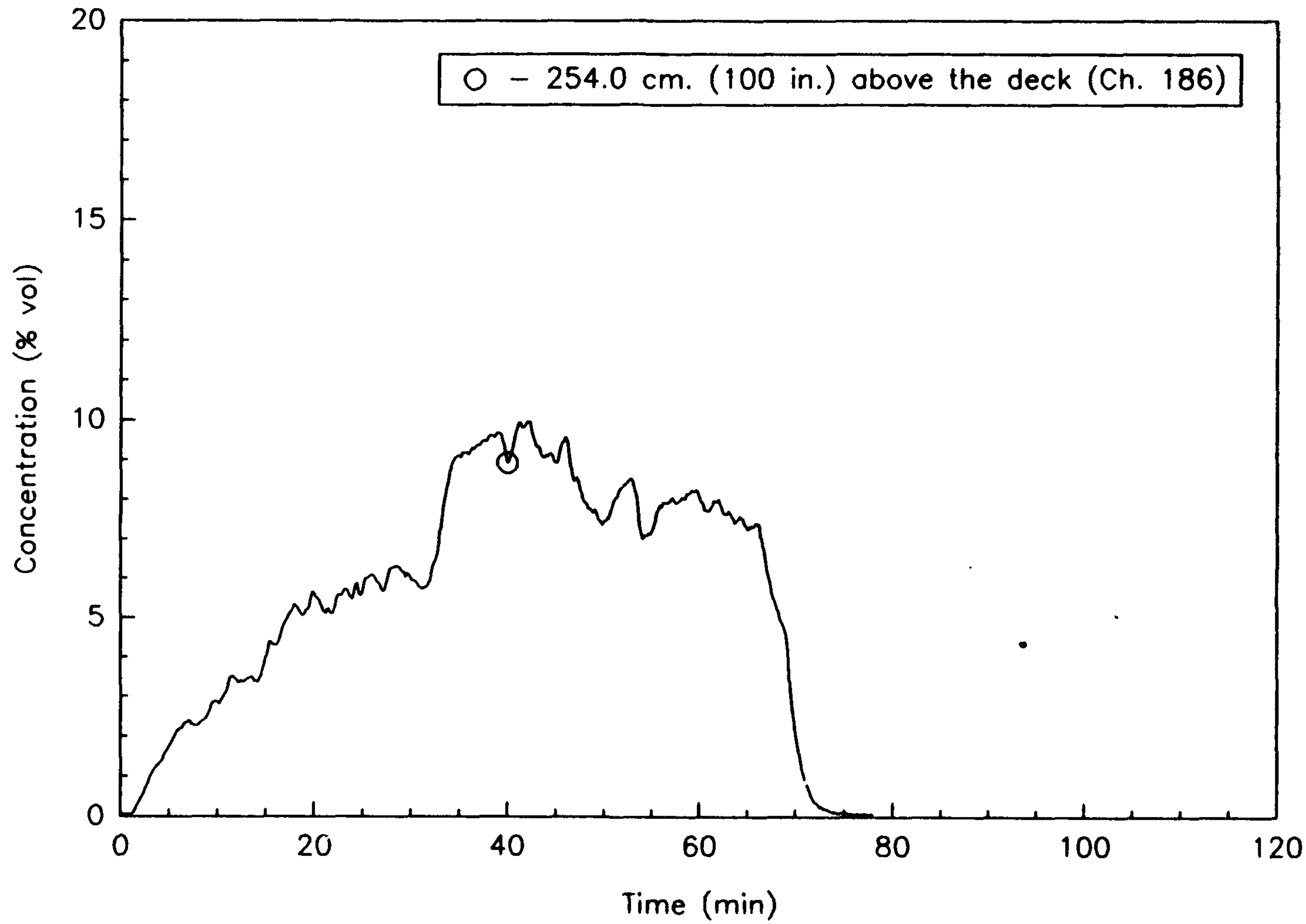

Fig. B46 – Carbon dioxide concentration at 3–20–2

FD_F3

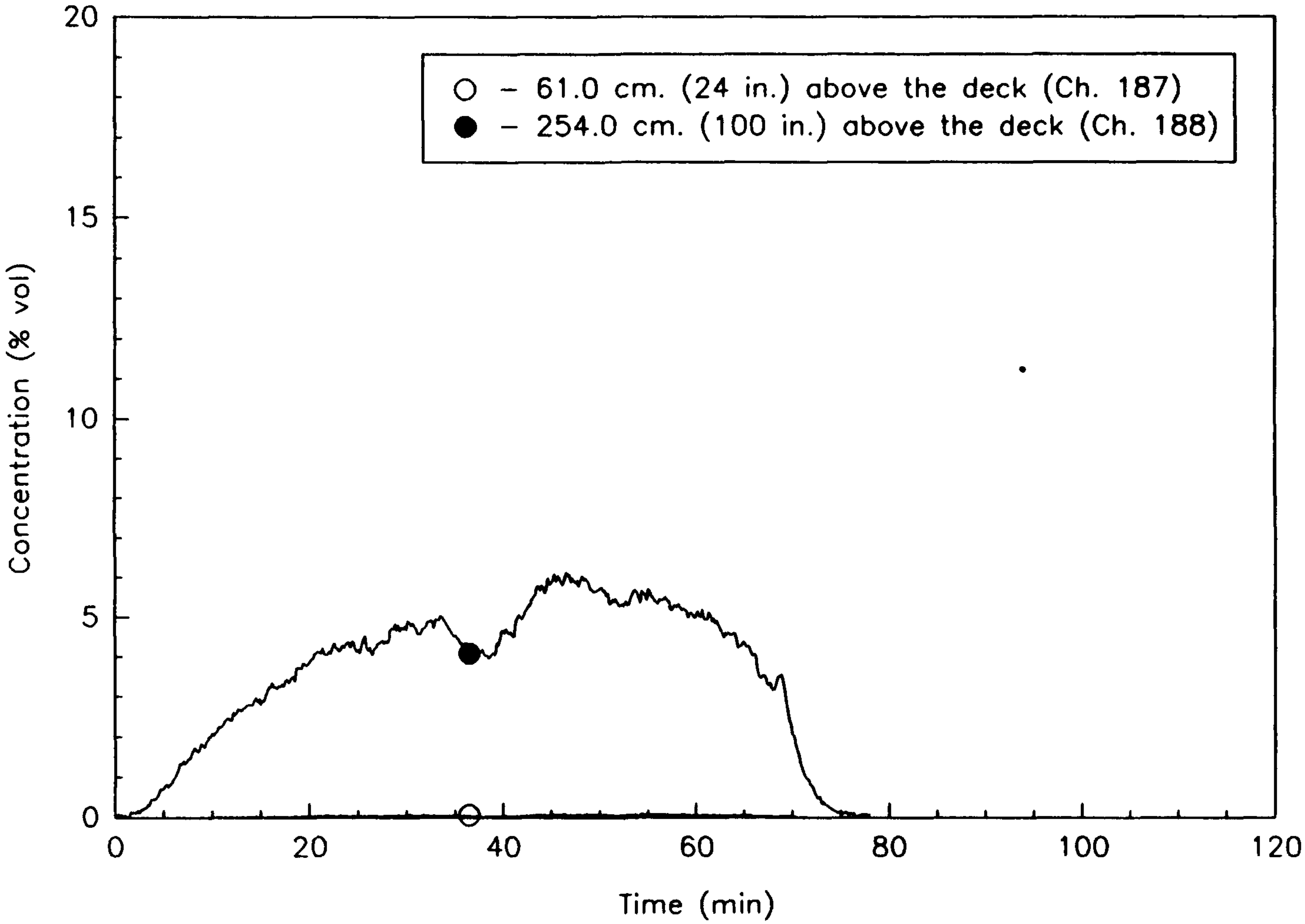

Fig. B47 – Carbon dioxide concentrations at 2–17–2

FD_F3

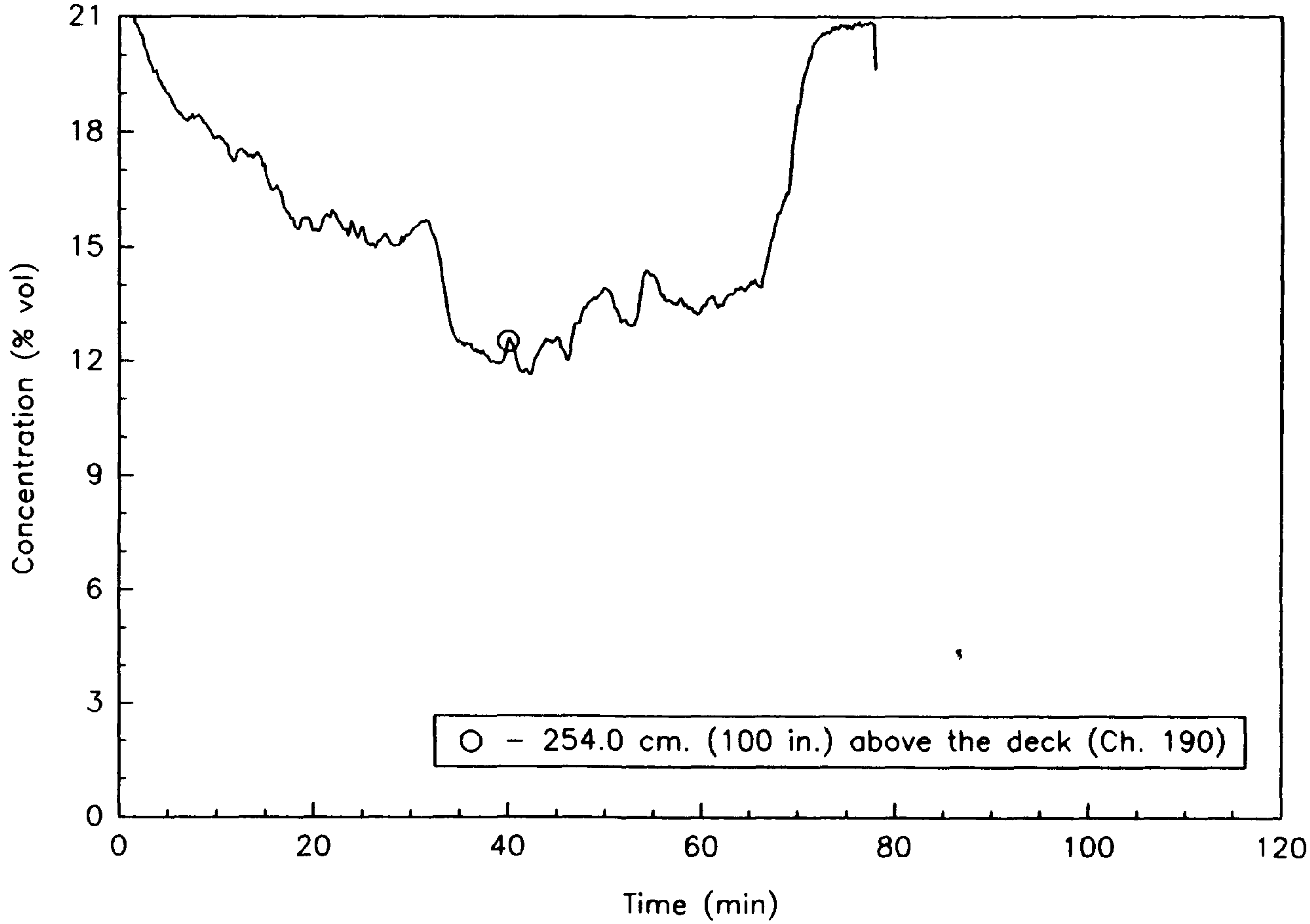

Fig. B48 – Oxygen concentration at 3–20–2

FD_F3

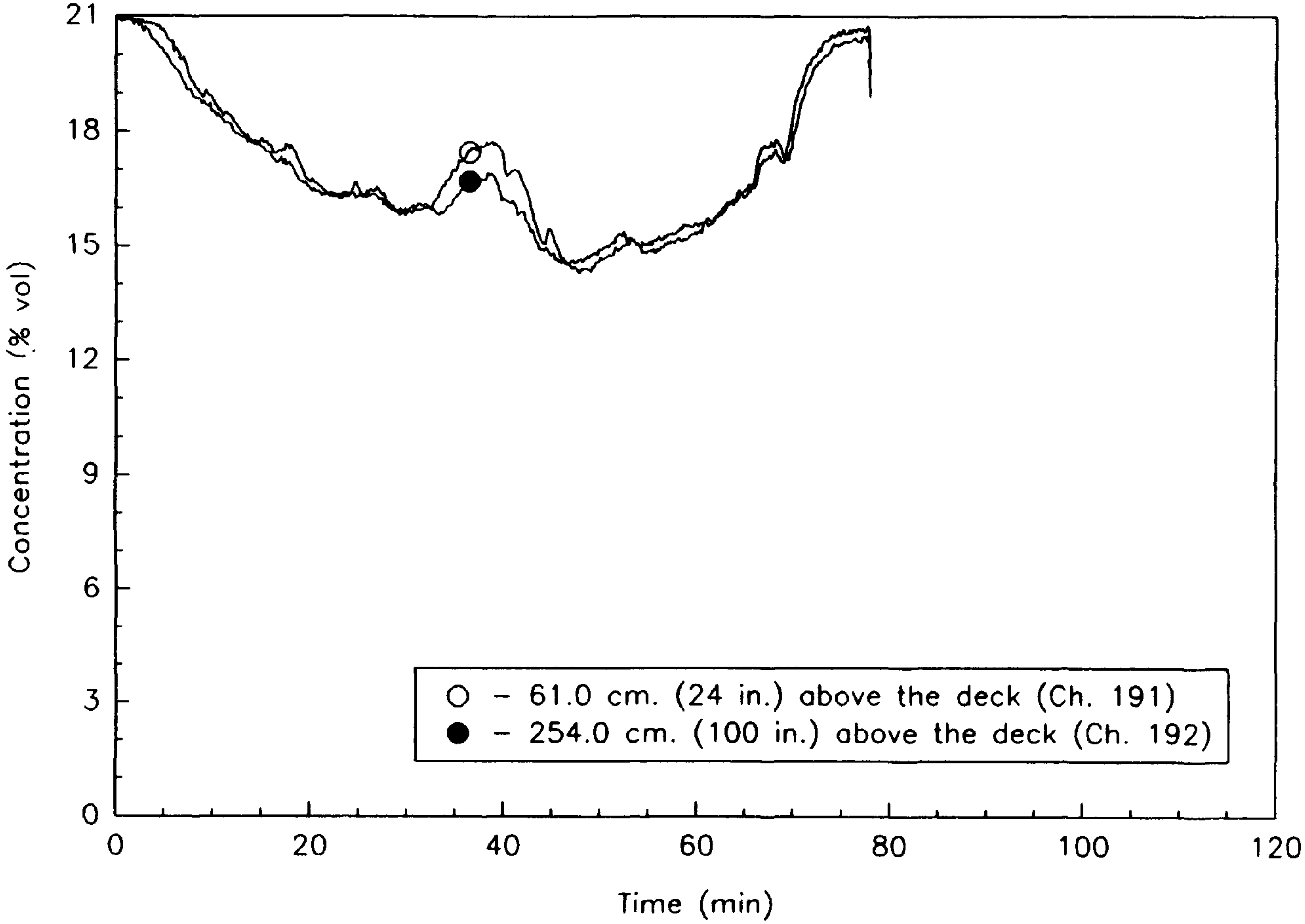

Fig. B49 – Oxygen concentrations at 2–17–2

FD_F3

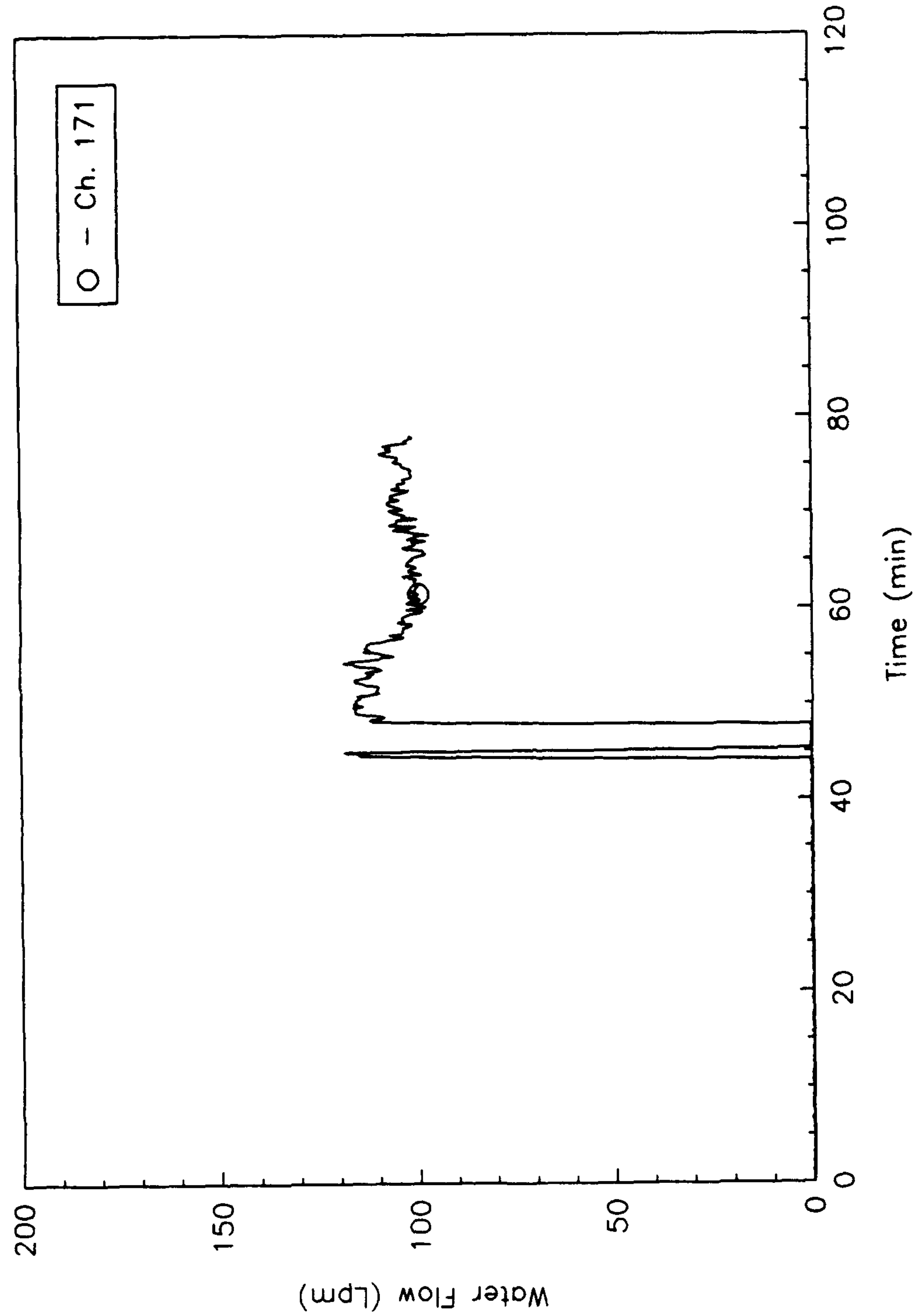

Fig. B50 - Water flow rate at 2-11-0

FD_F3

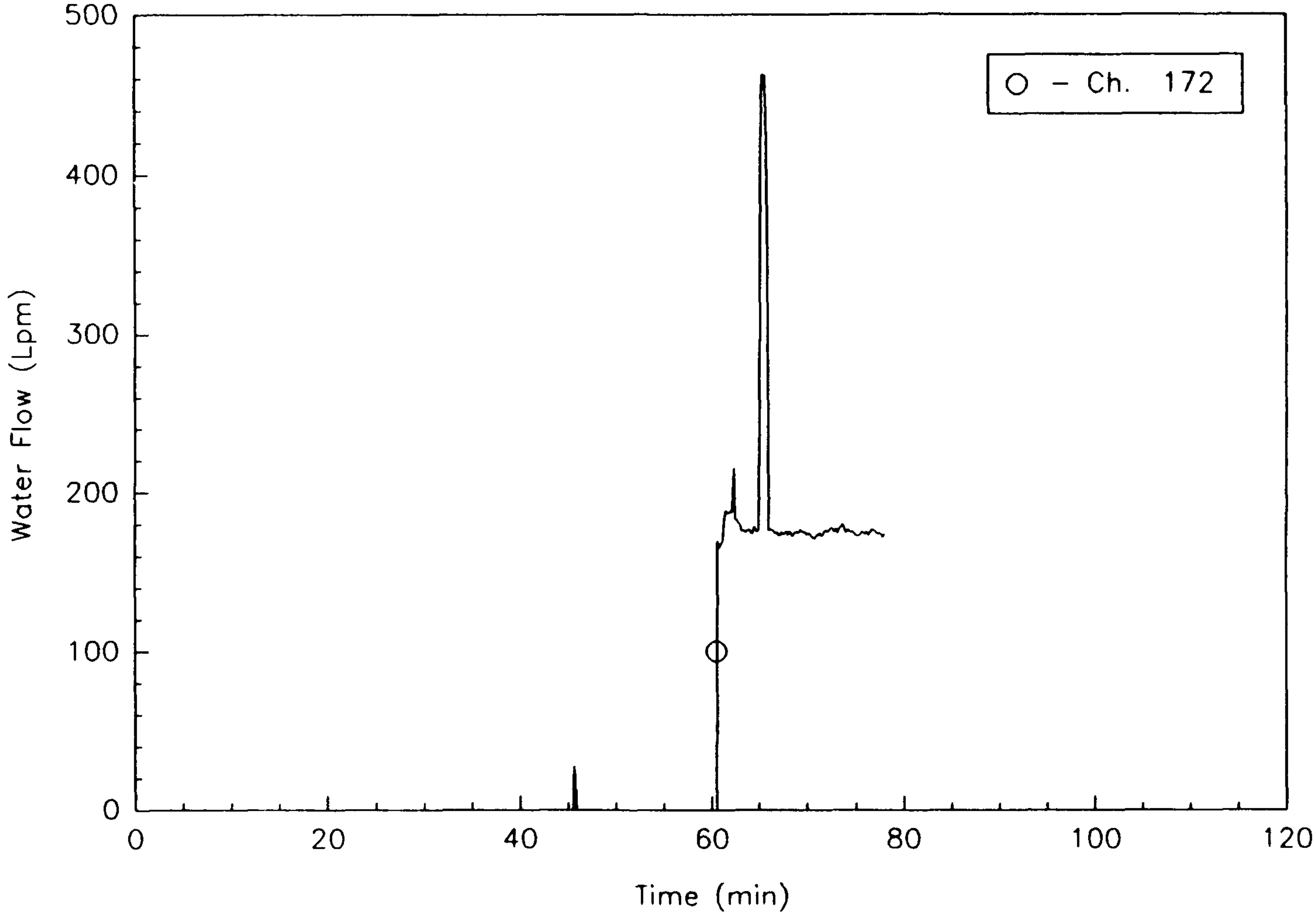

Fig. B51 - Water flow rate at 2-19-1

FD_F3

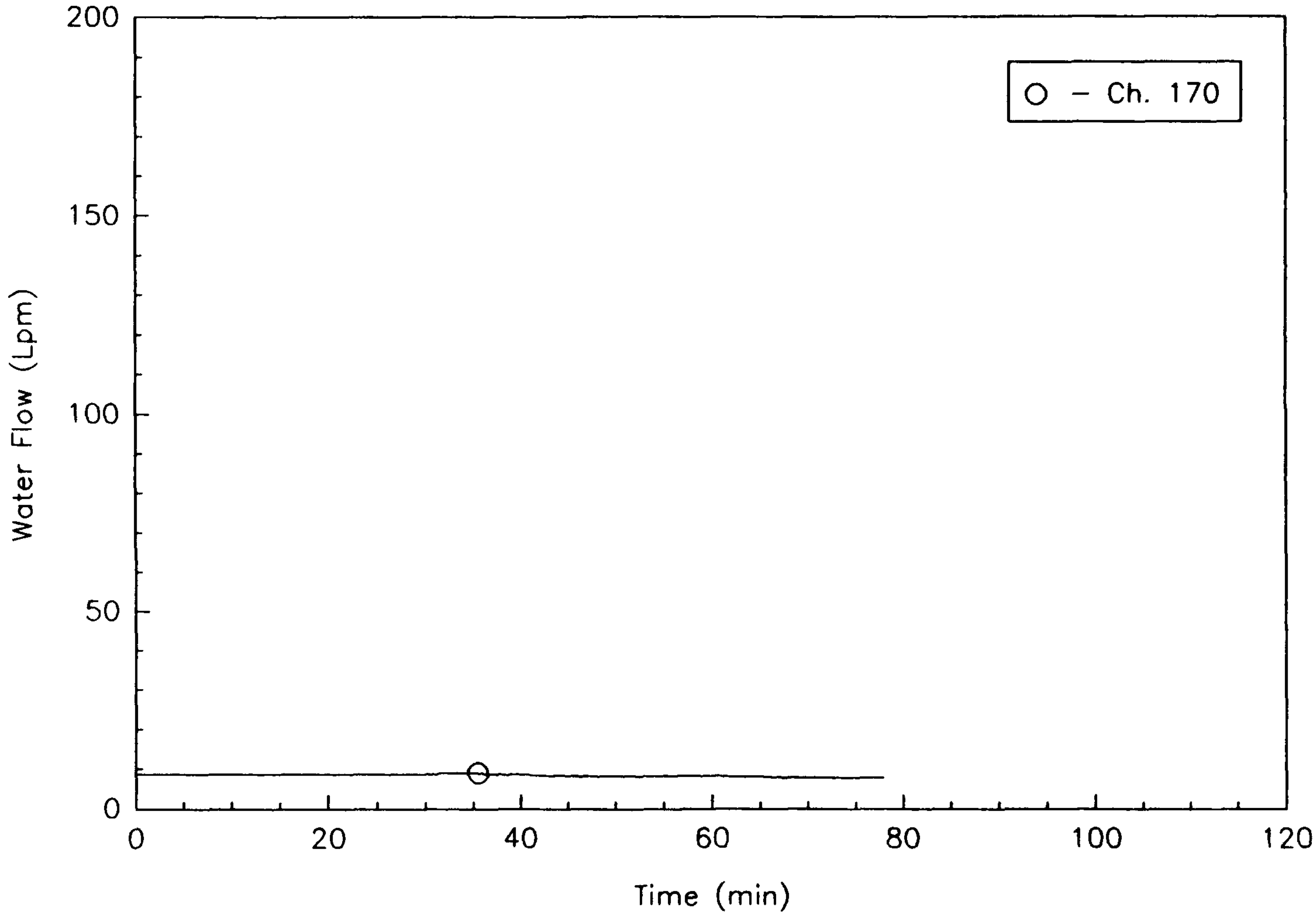

Fig. B52 – Water flow at 2-28-1

FD__F3

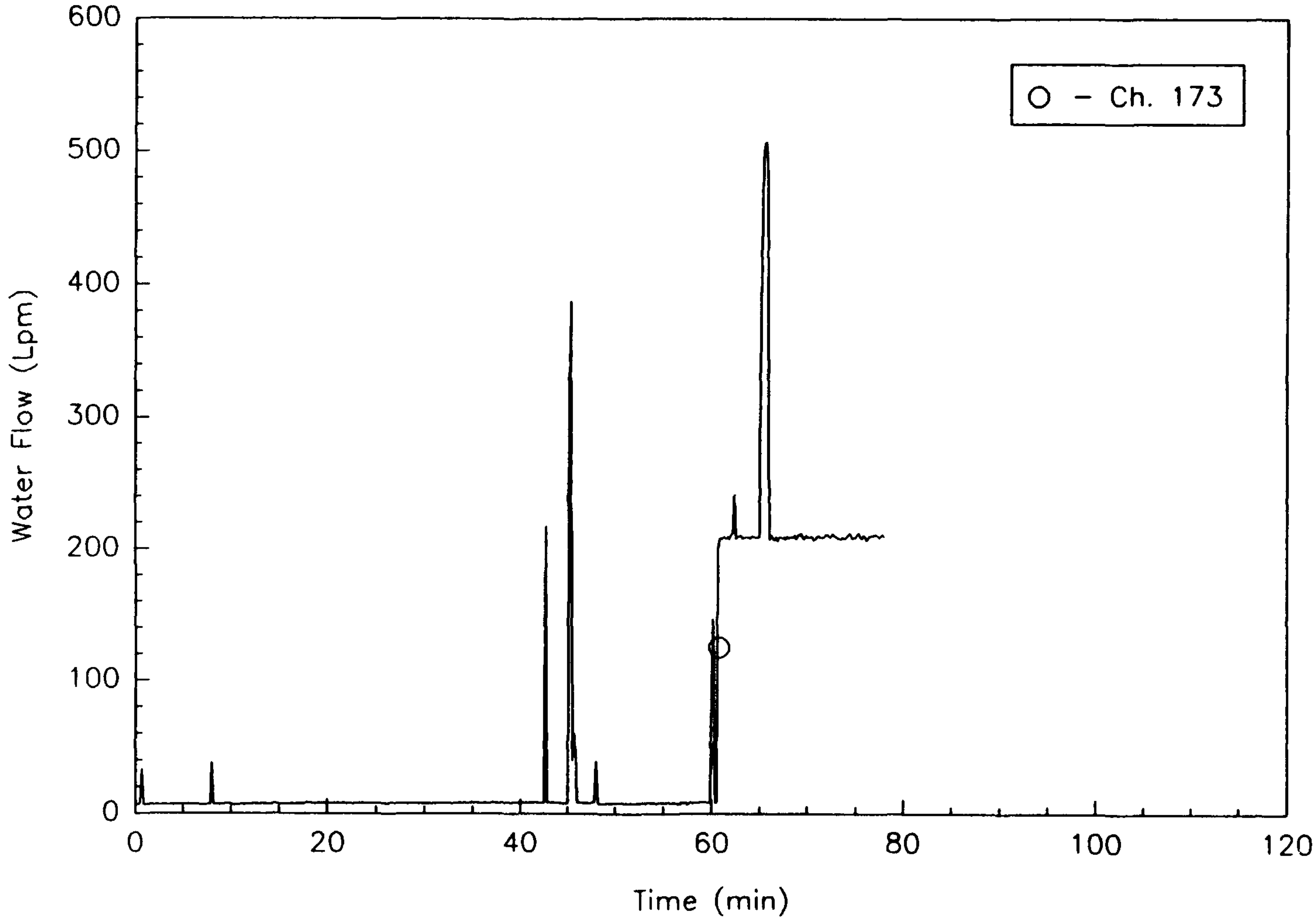

Fig. B53 - Water flow at 1-23-1

FD_F3

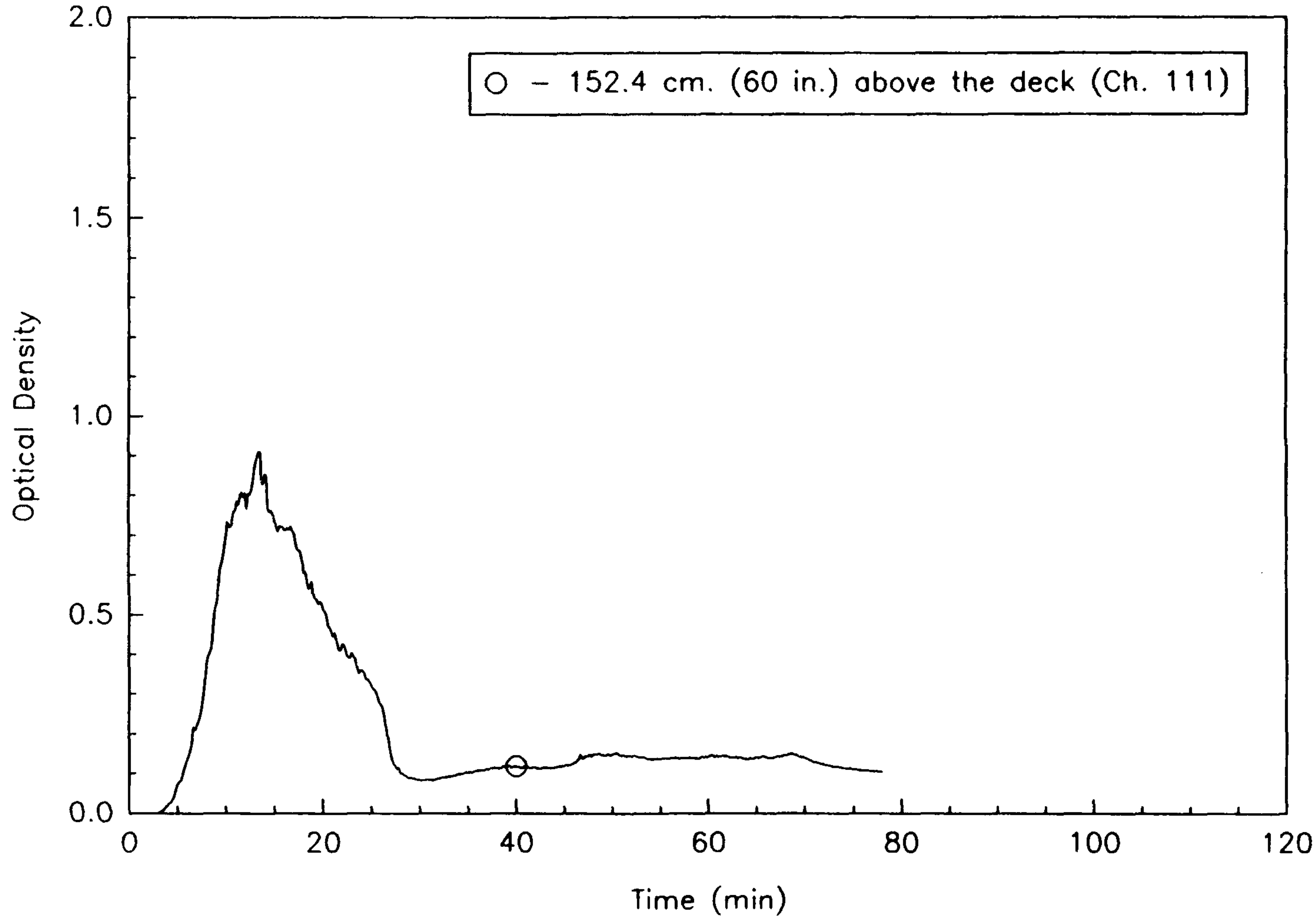

Fig. B54 – Optical density at 2–16–1 in Crew Living 1

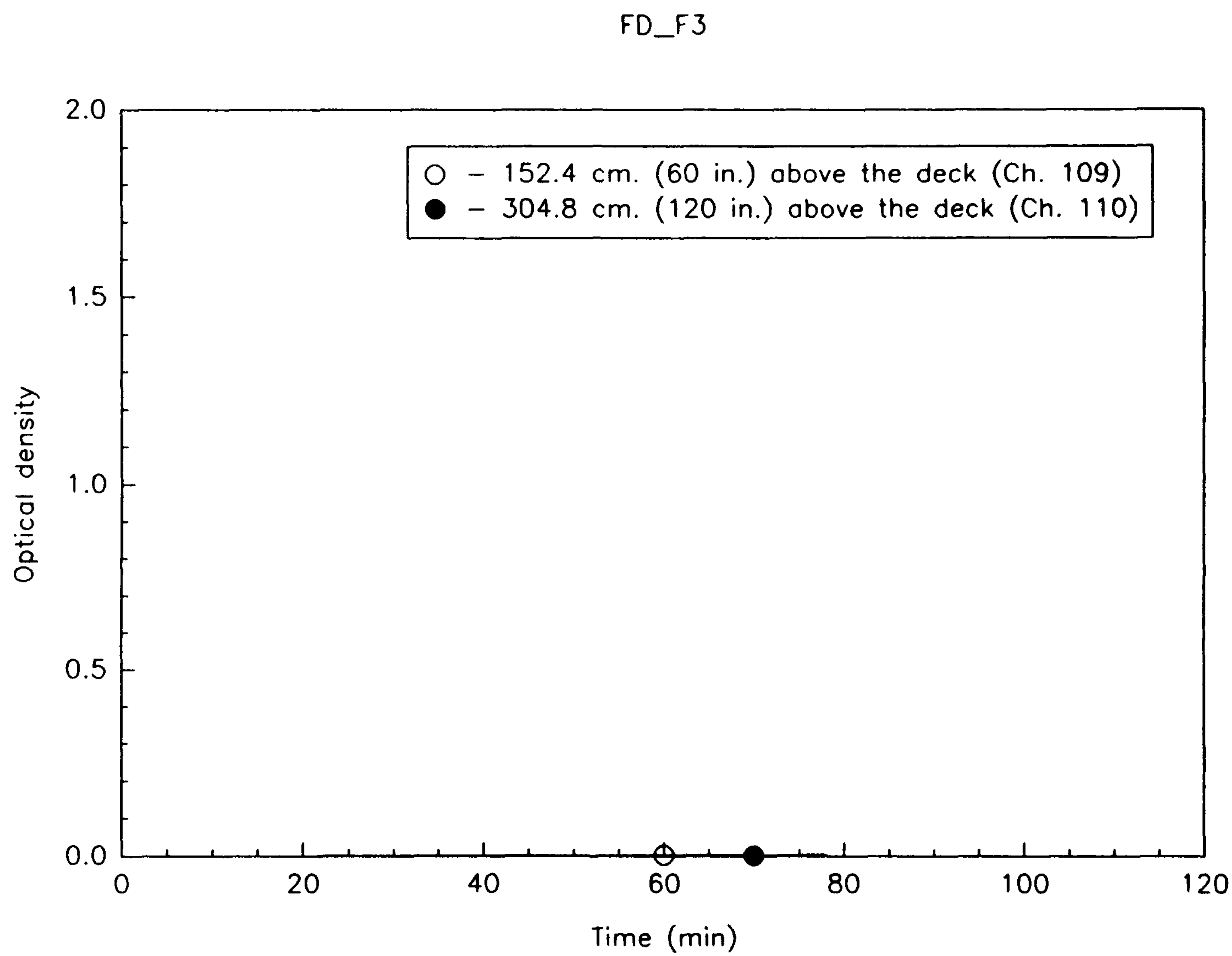

Fig. B55 – Optical density at 2-26-2 in CIC AFT

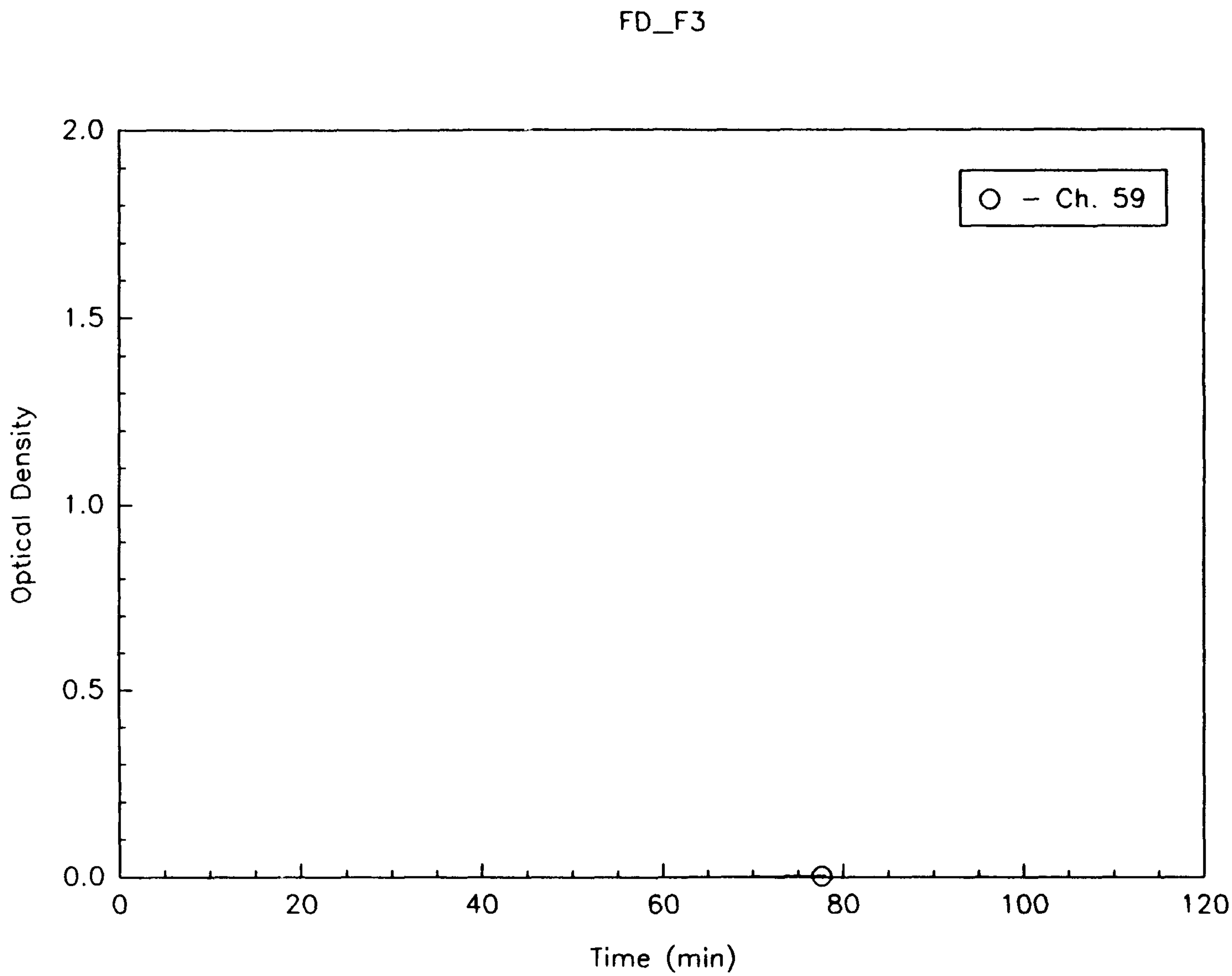

Fig. B56 – Optical density at 2–18–2 in port passageway
304.8 cm. (120 in.) above the deck

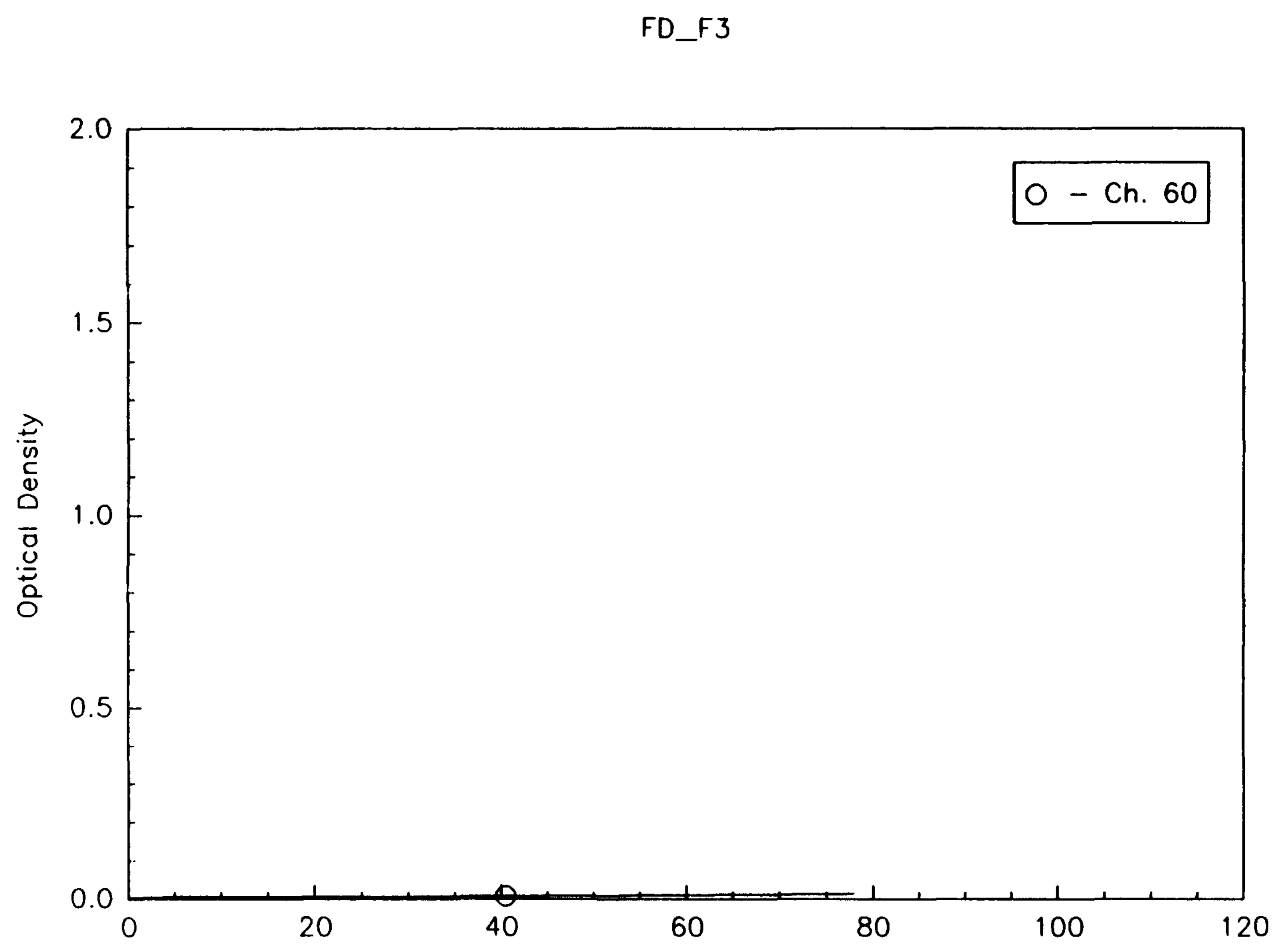

Fig. B57 – Optical density at 2–23–2 in the port passageway 152.4 cm. (60 in.) above the deck

FD_F3

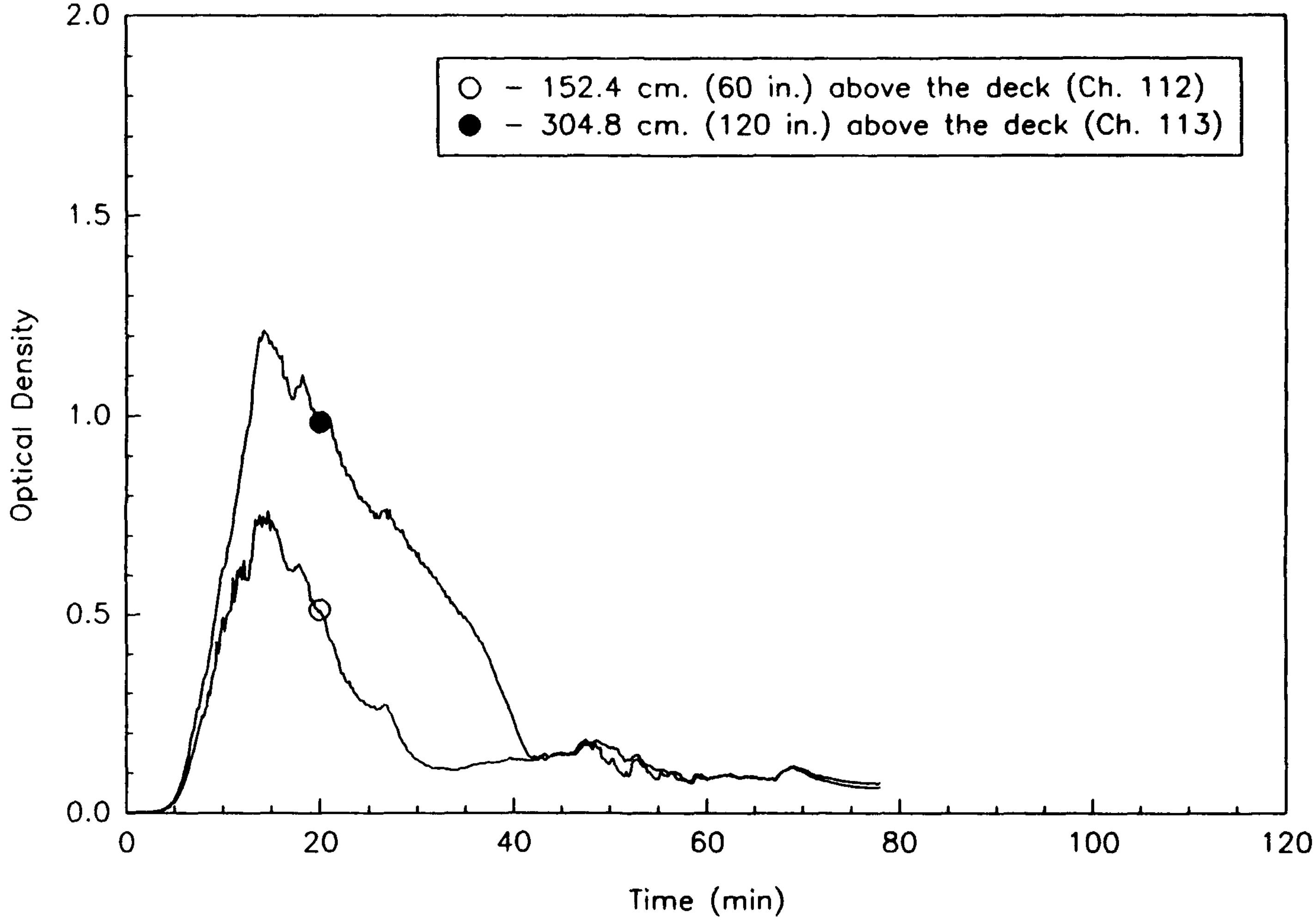

Fig. B58 – Optical density at 2–19–1 starboard passageway

FD_F3

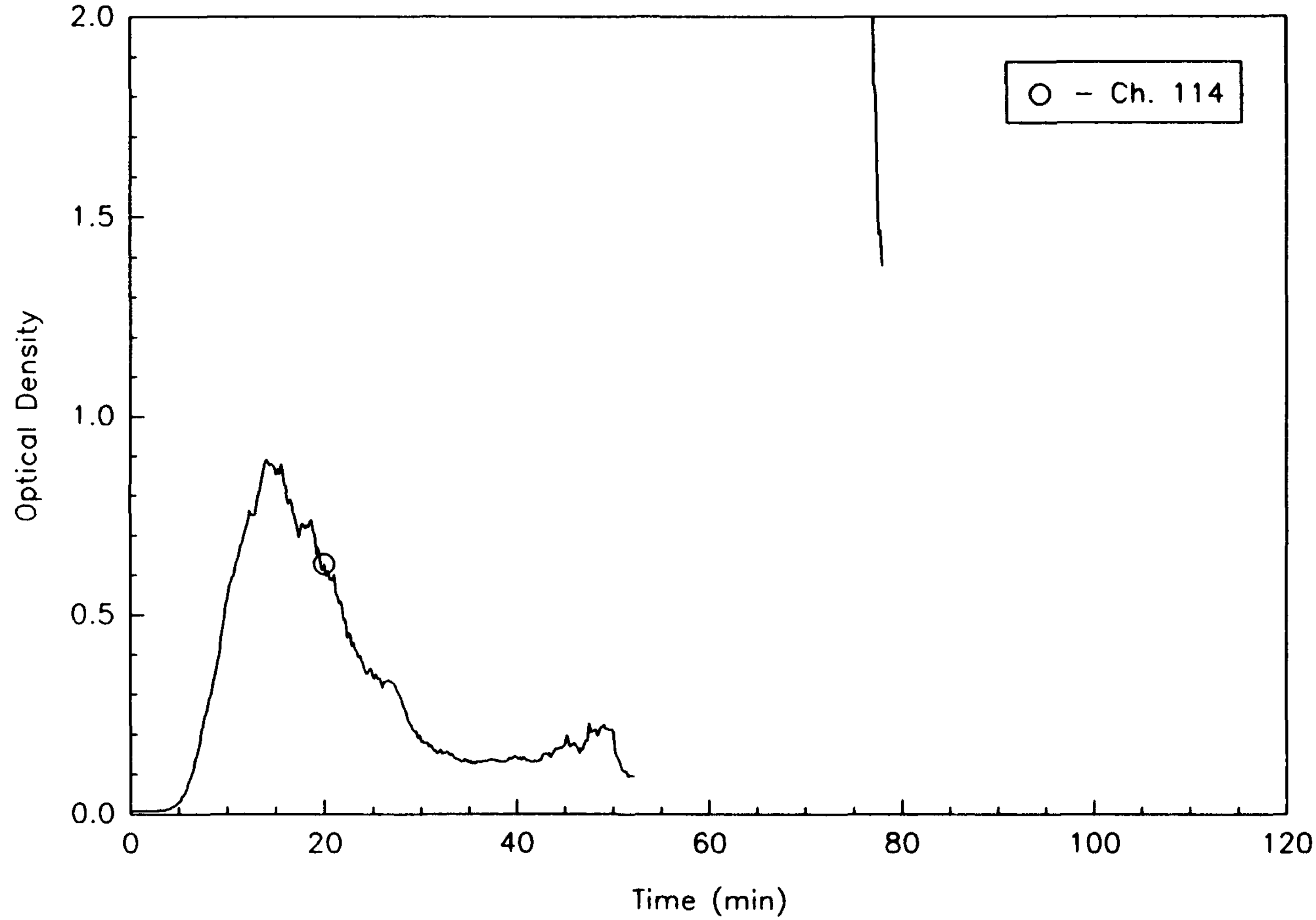

Fig. B59 – Optical density at 2–24–1 in the starboard passageway 152.4 cm. (60 in.) above the deck

FD_F3

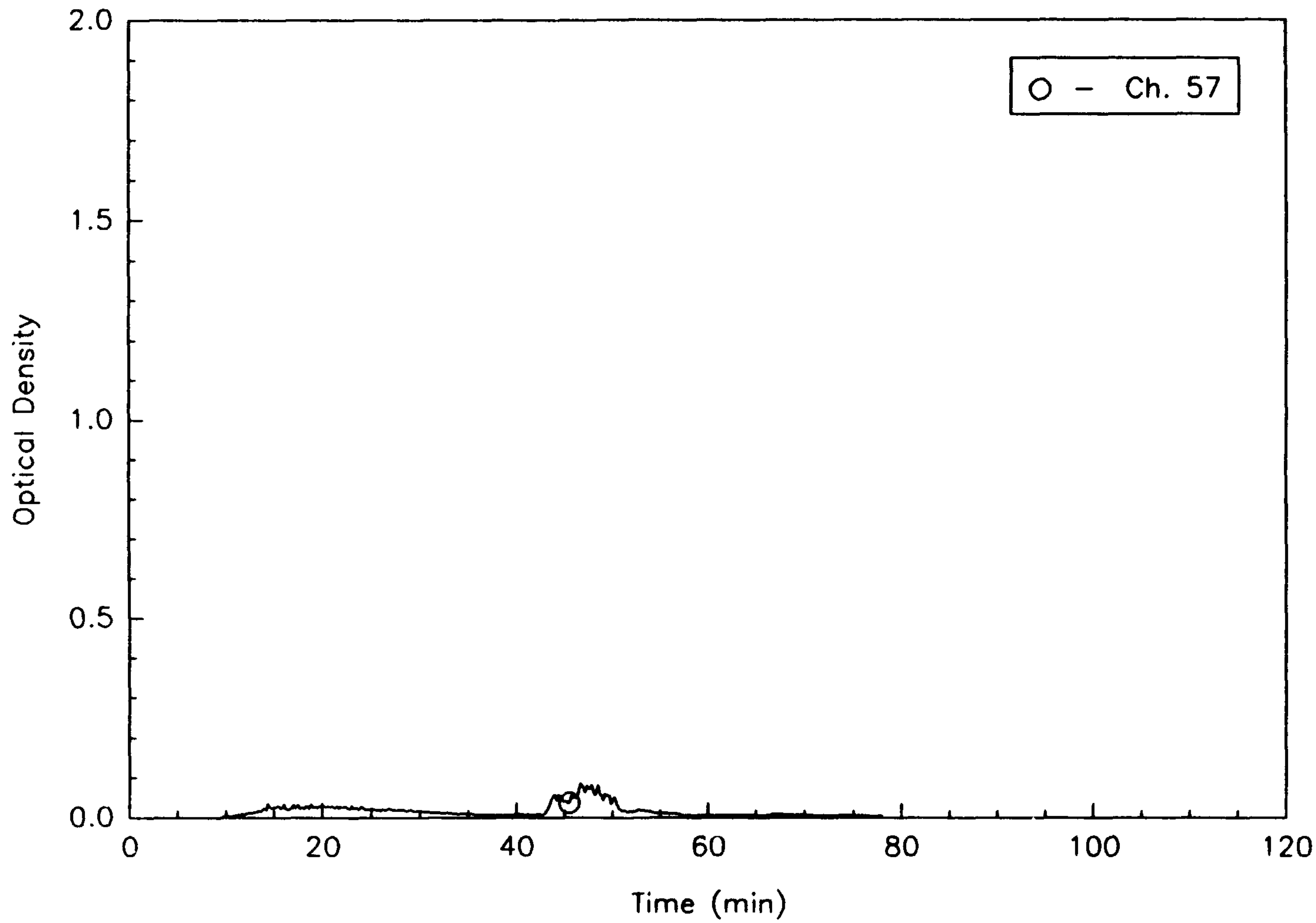

Fig. B60 – Optical density at 2–13–0 athwartship passageway

FD_F3

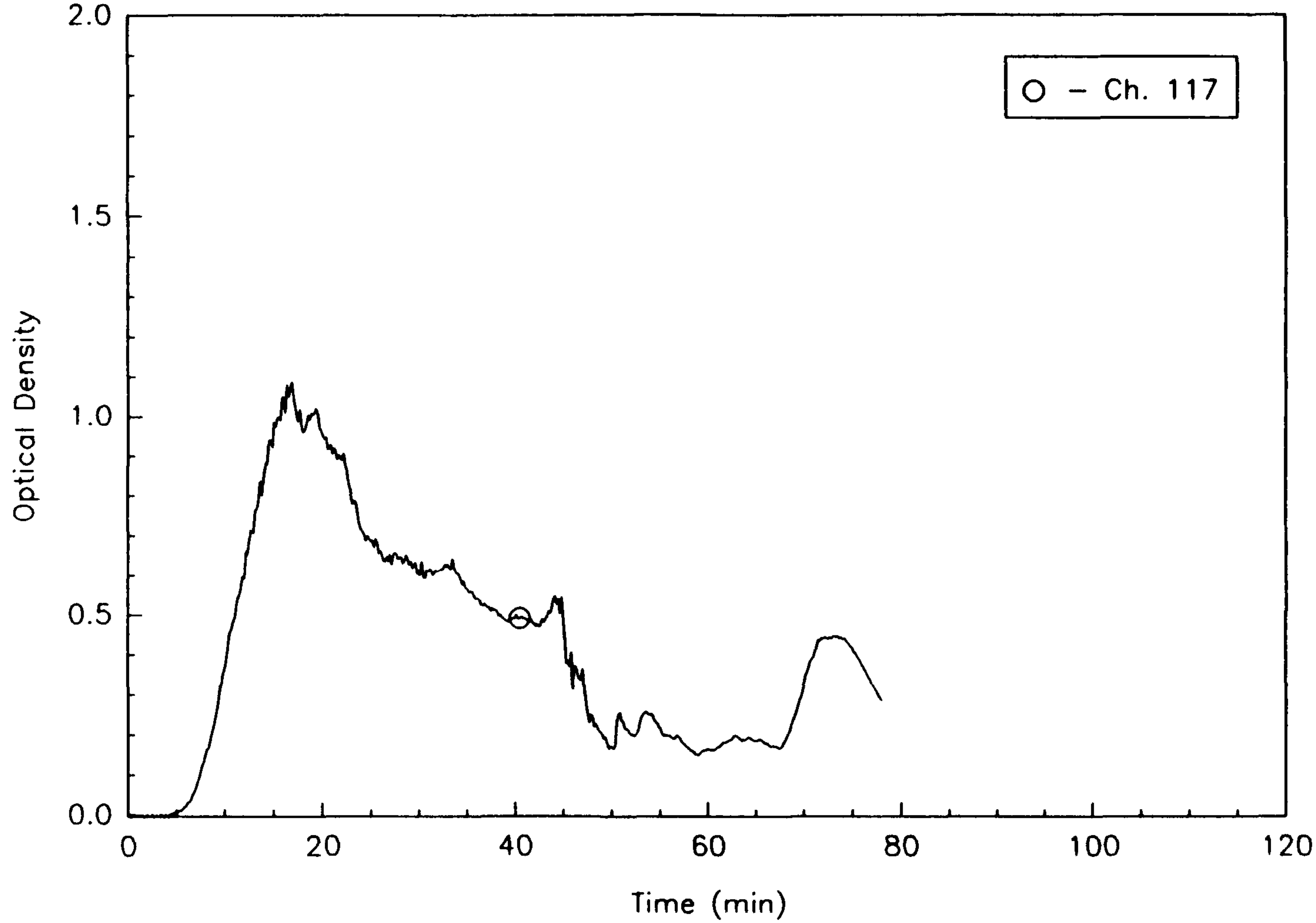

Fig. B61 – Optical density at 1–26–1 in the starboard passageway 152.4 cm. (60 in.) above the deck

FD_F3

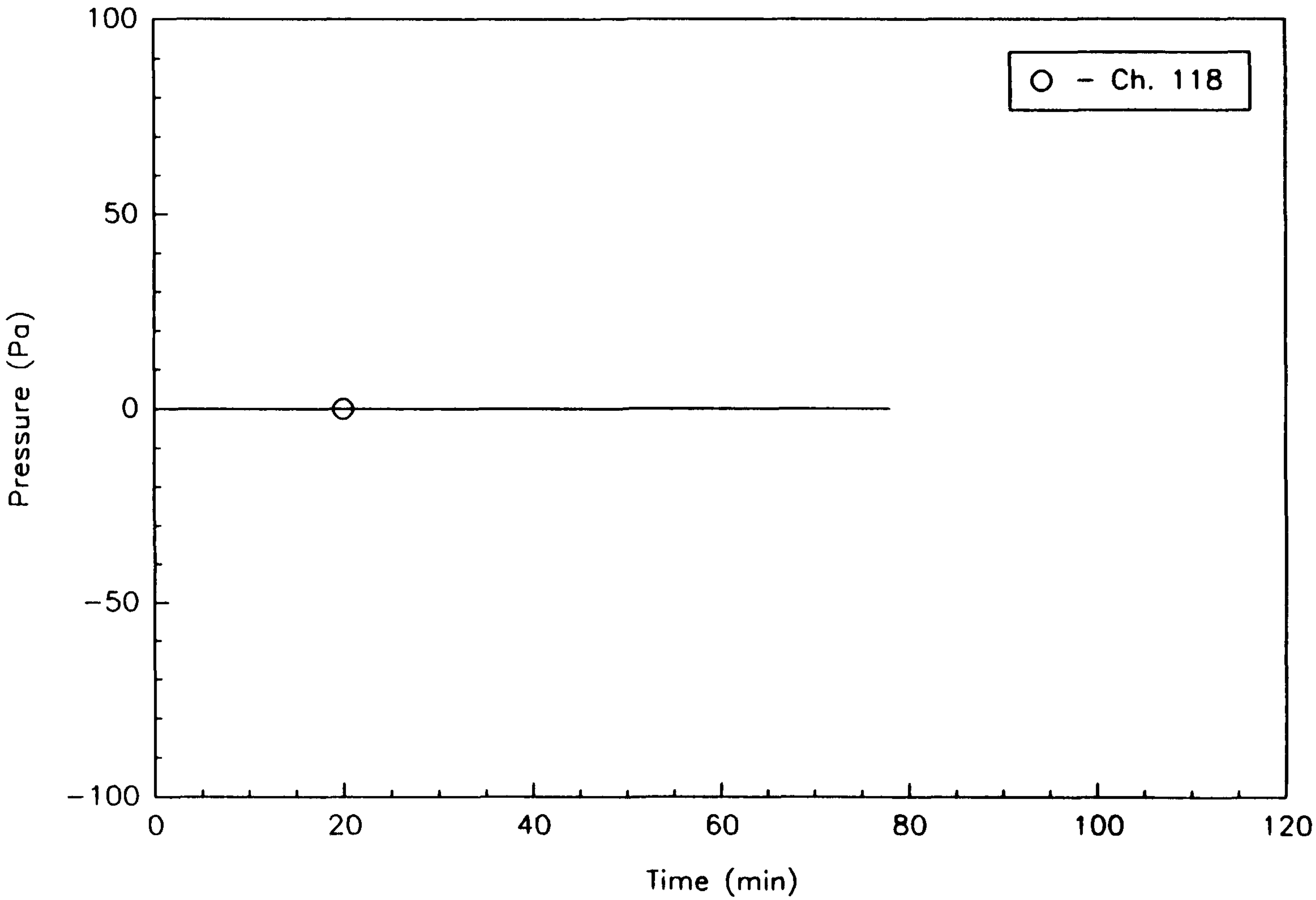

Fig. B62 - Differential pressure at QAWTD 2-15-3

FD_F3

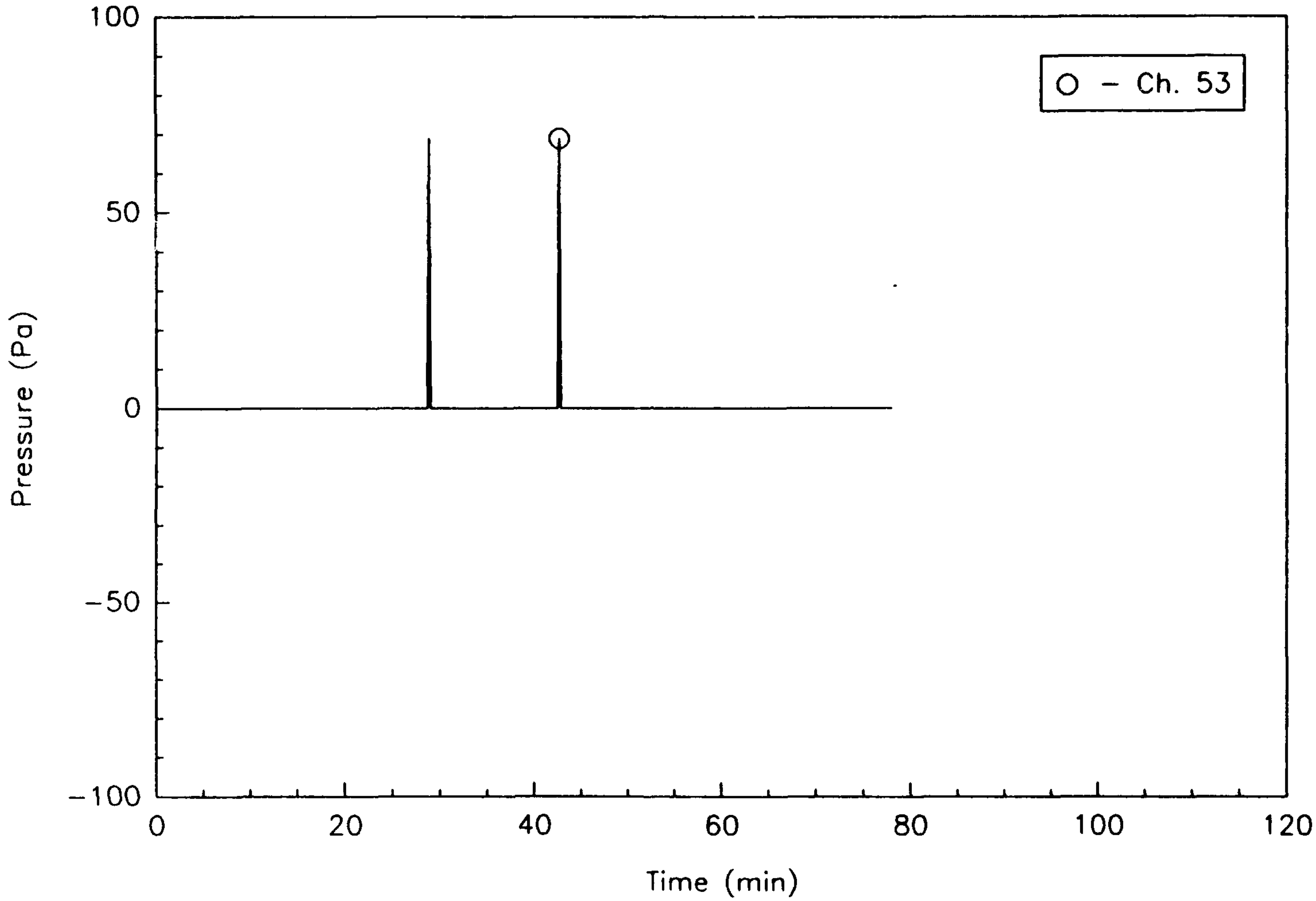

Fig. B63 – Differential pressure at QAWTD 2-17-1

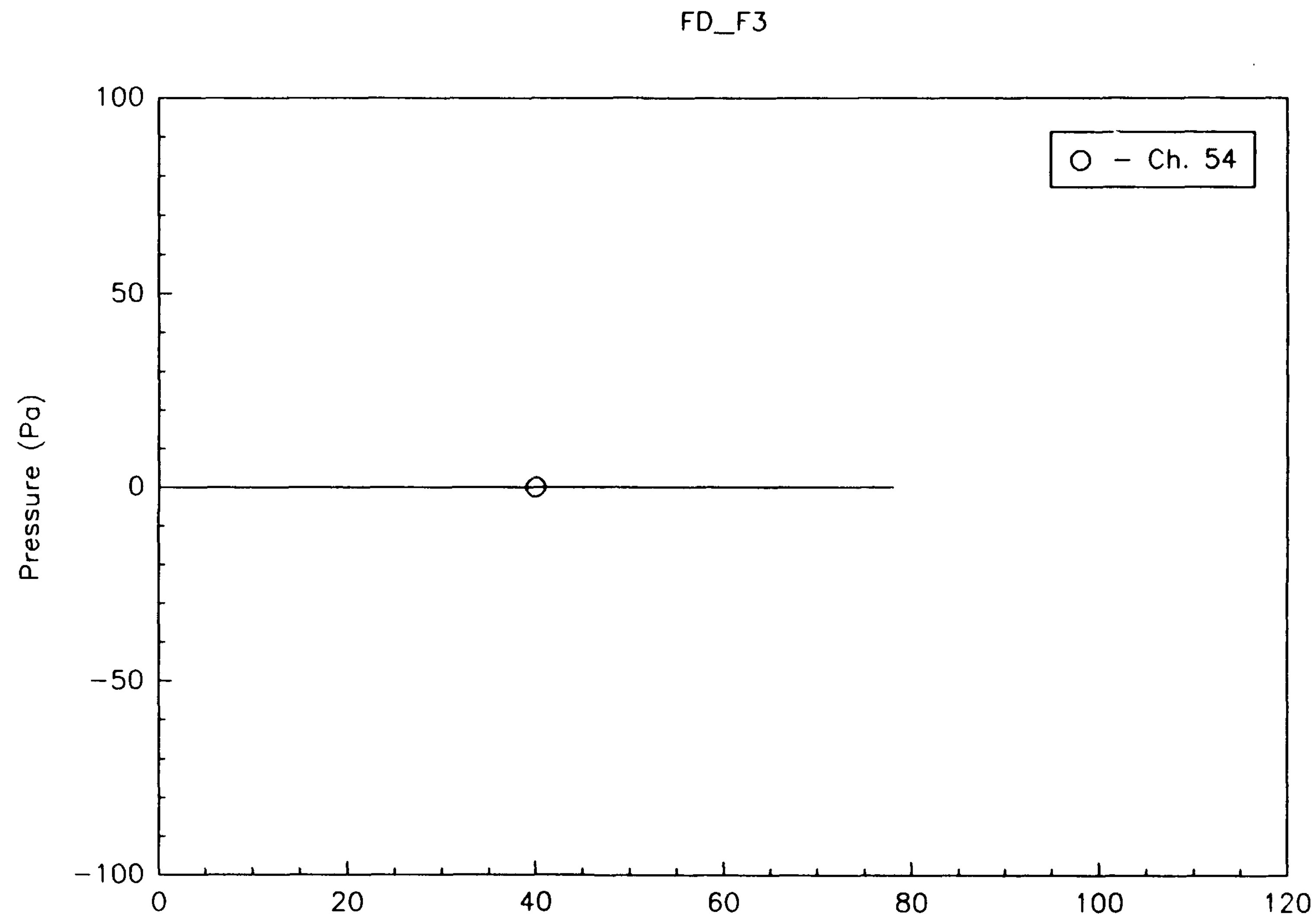

Fig. B64 – Differential pressure at QAWTH 2-20-2

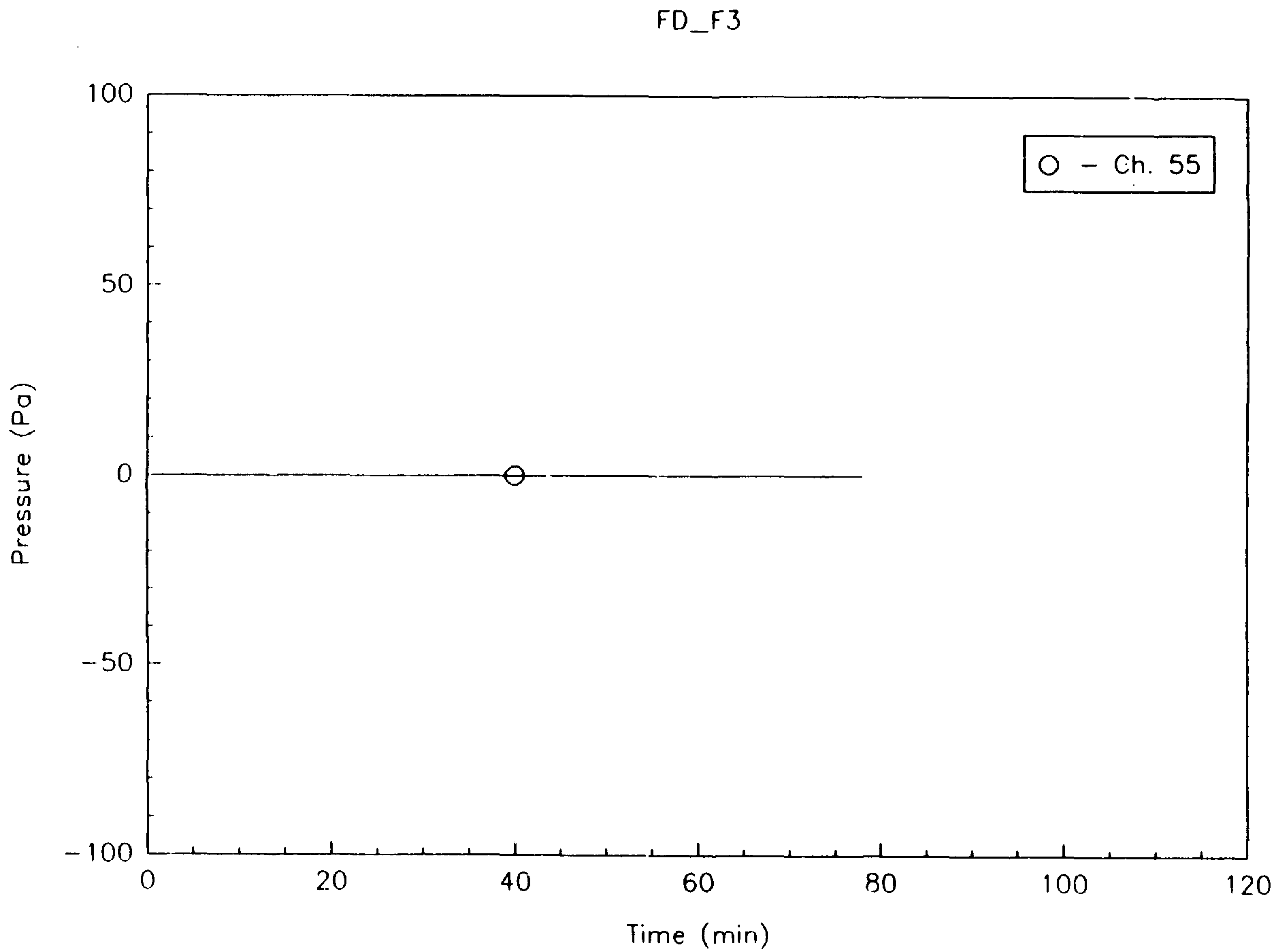

Fig. B65 - Differential pressure at WTS 2-21-1

FD_F3

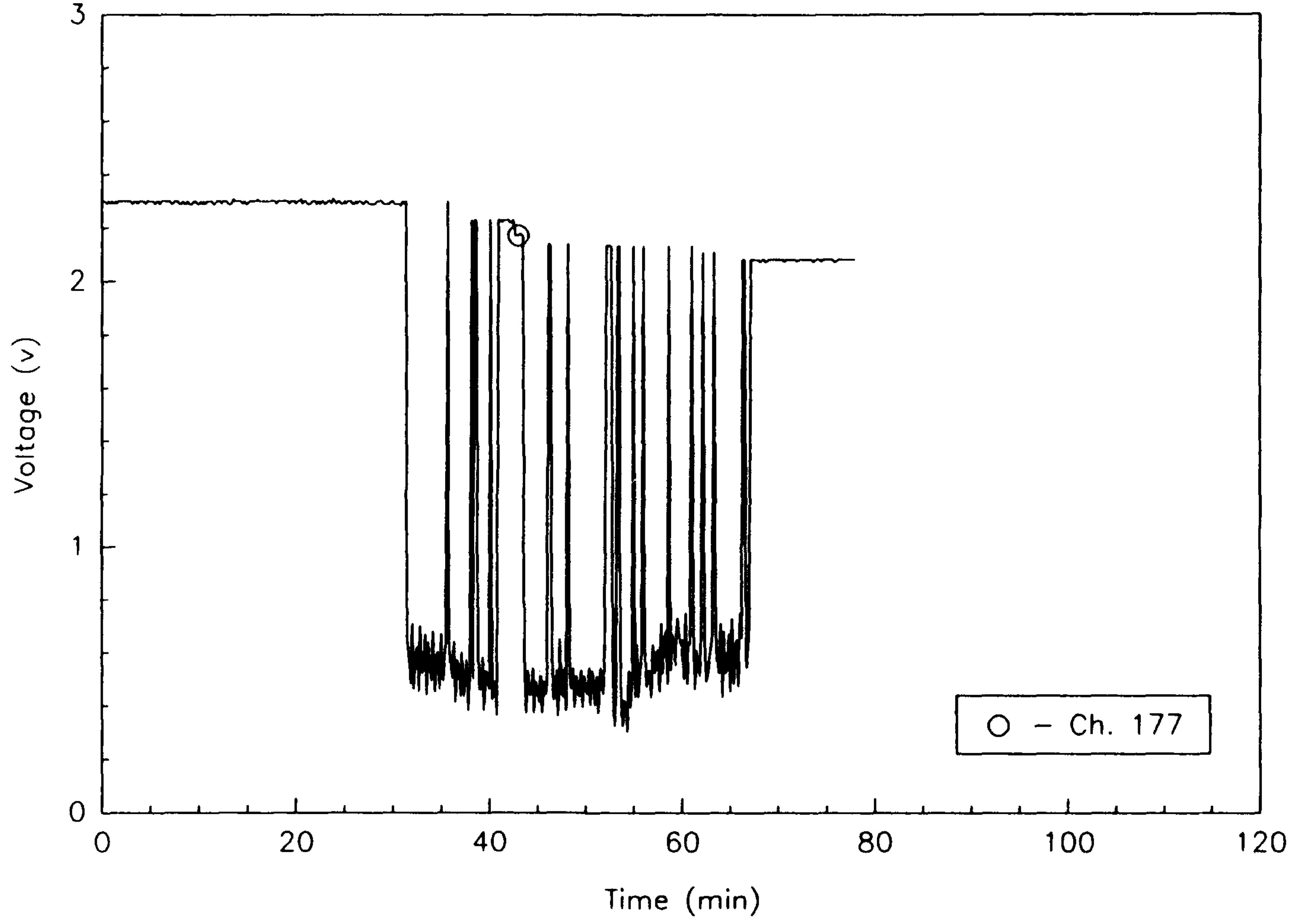

Fig. B66 - Micro switch at QAWTD 3-22-1

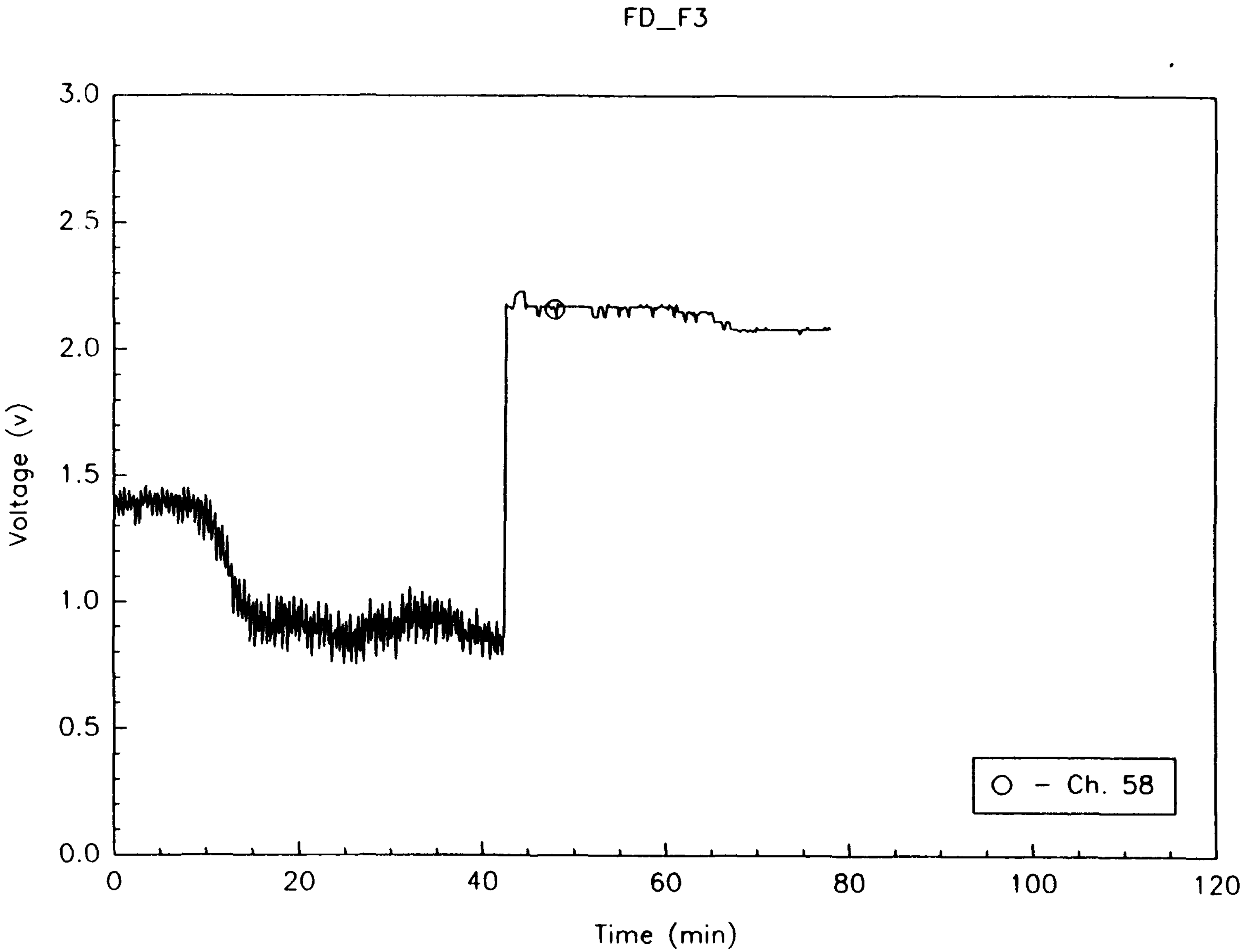

Fig. B67 – Micro switch at QAWTD 2–15–3

FD_F3

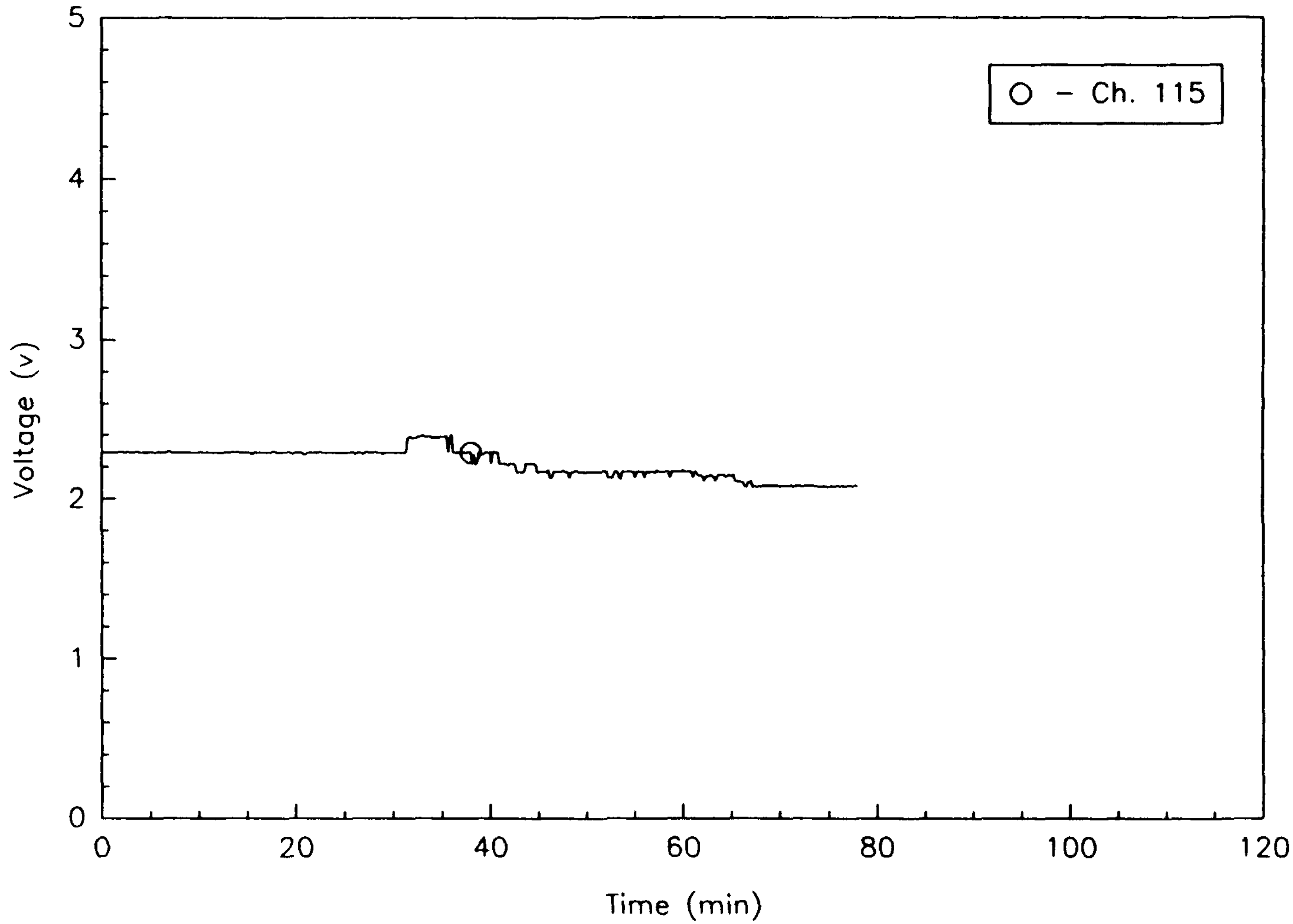

Fig. B68 – Micro switch at QAWTD 2-17-1

FD_F3

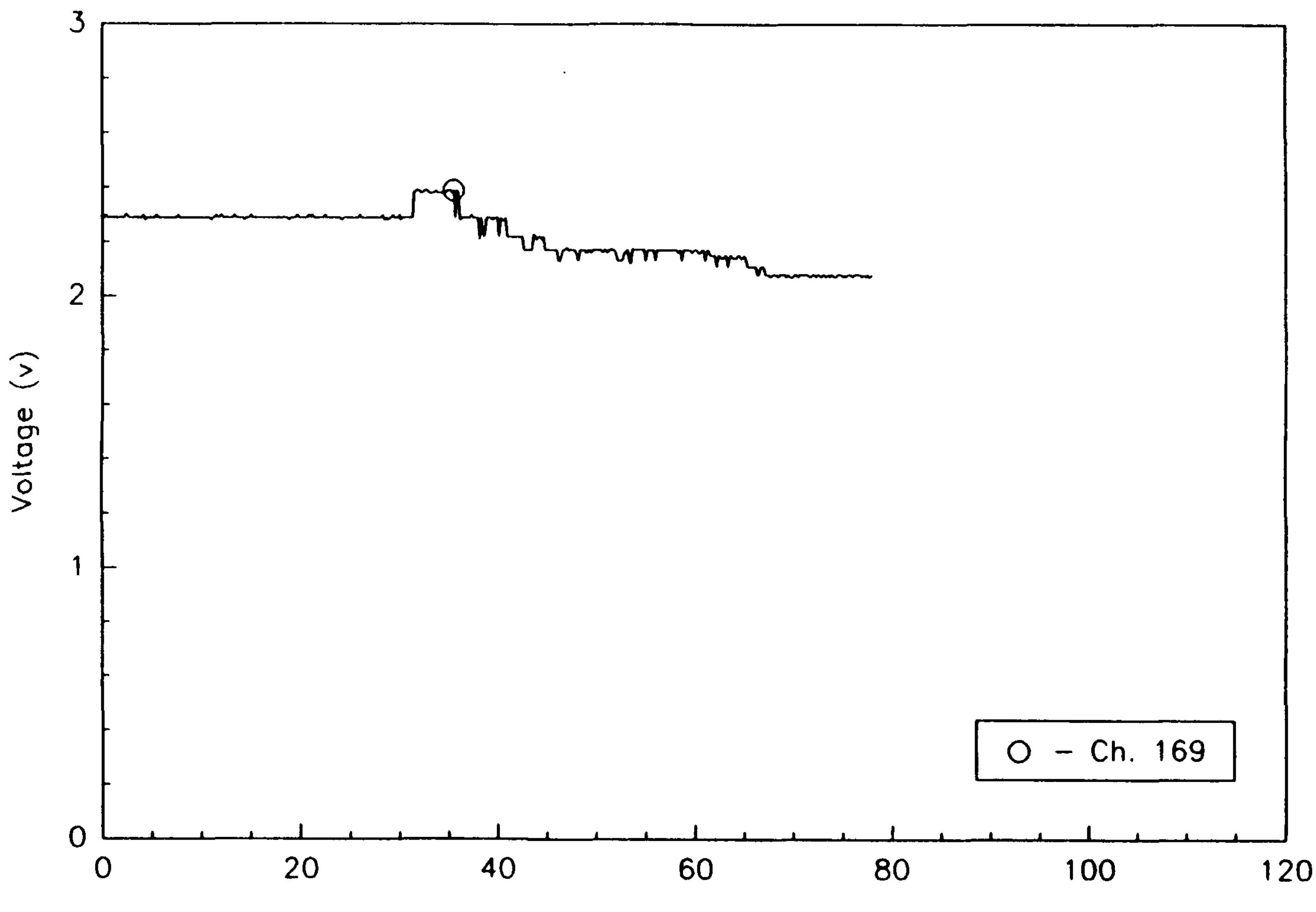

Fig. B69 - Micro switch at WTH 2-21-2

FD_F3

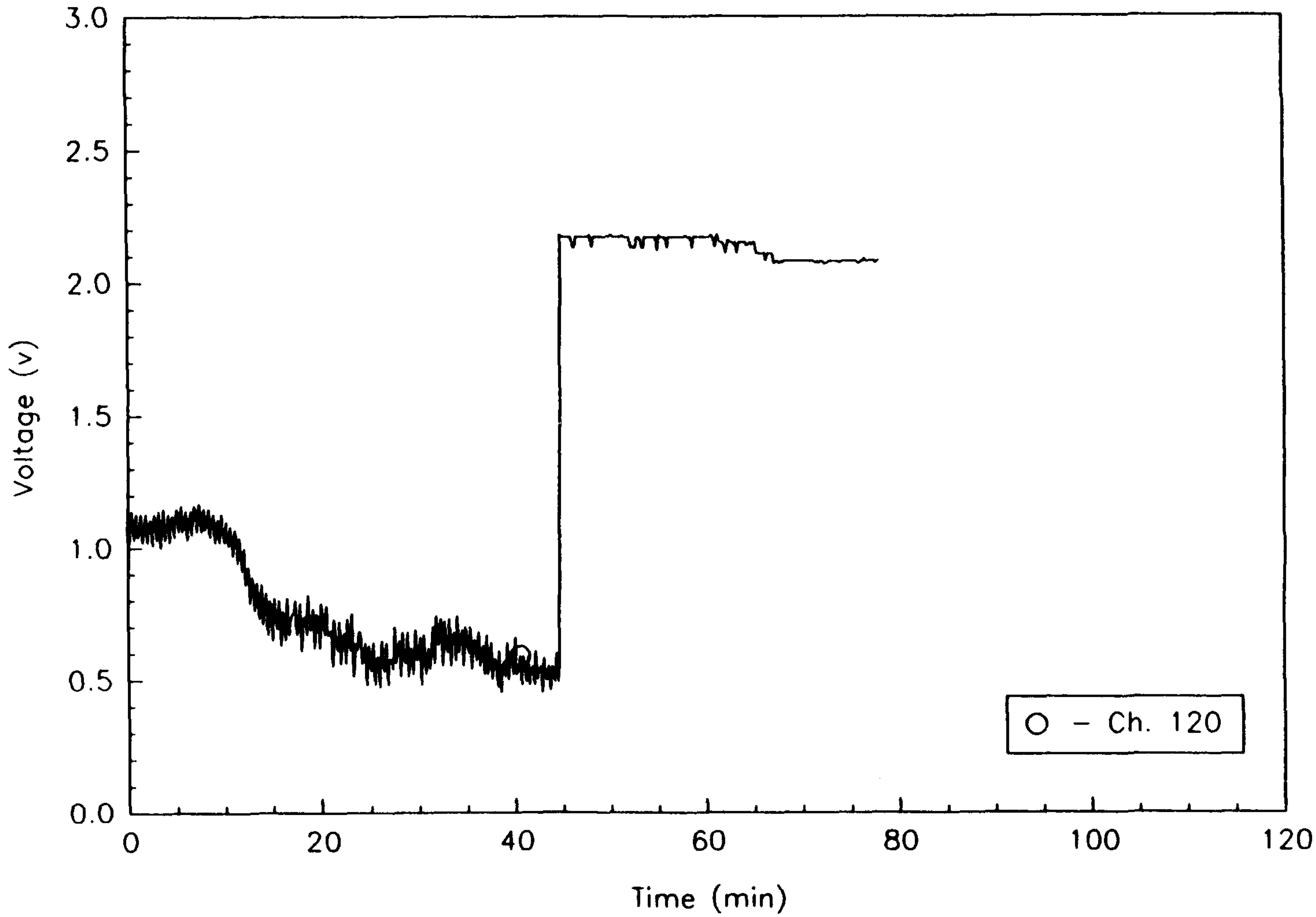

Fig. B70 - Micro switch at WTS 2-21-1

FD_F3

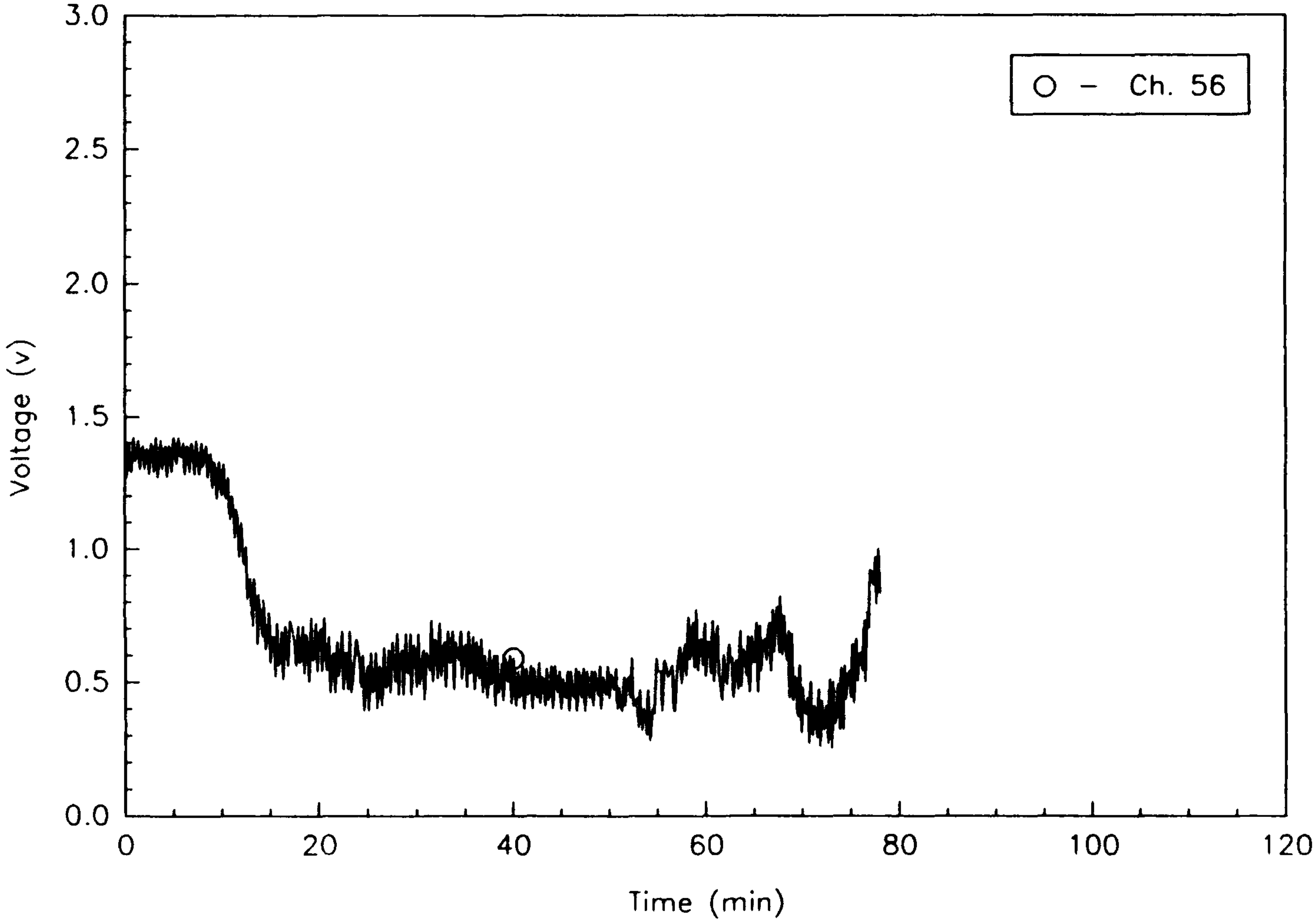

Fig. B71 – Micro switch at QAWTD 2–27–2

FD_F3

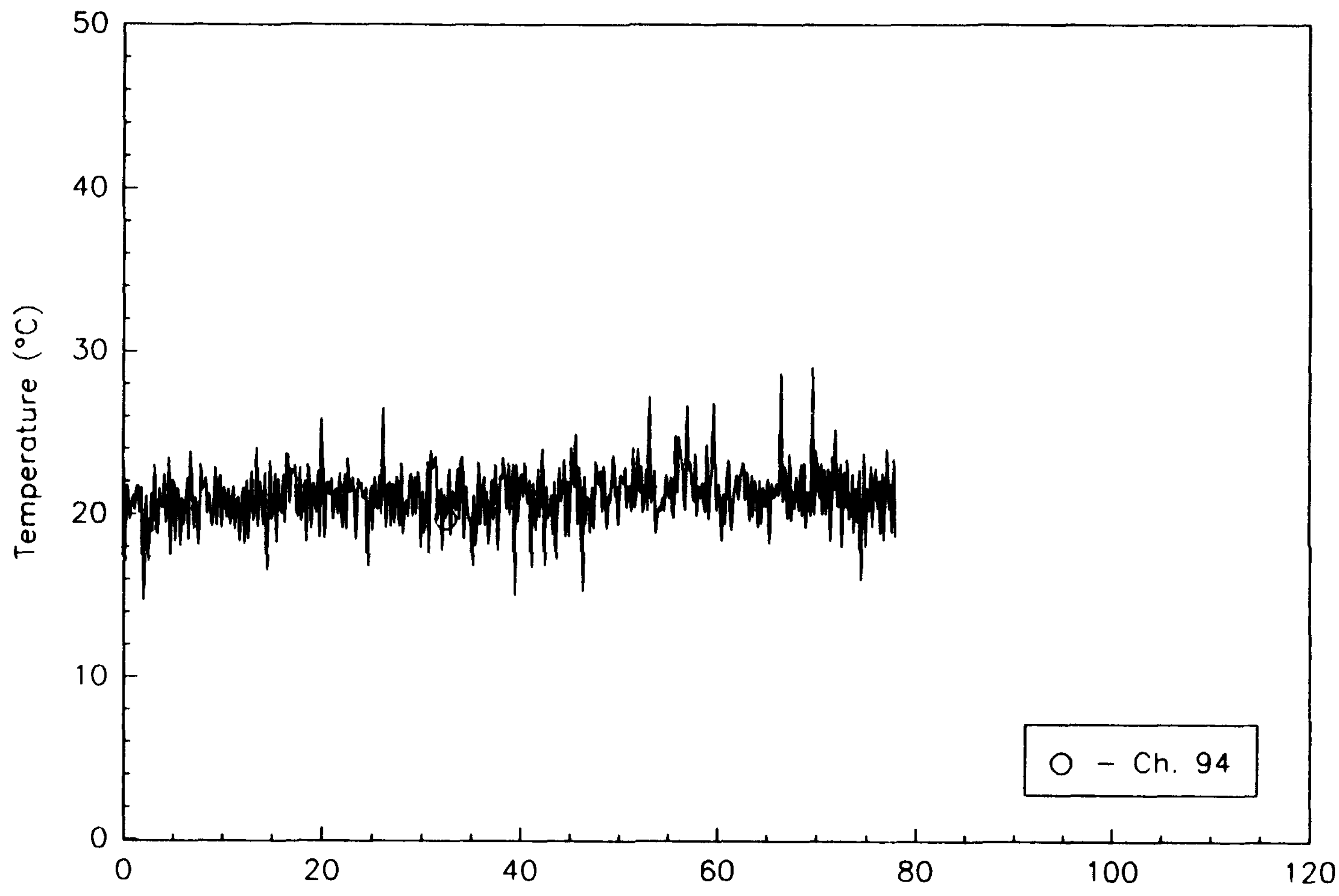

Fig. B72 – External air temperature at 2–48–0

FD_F3

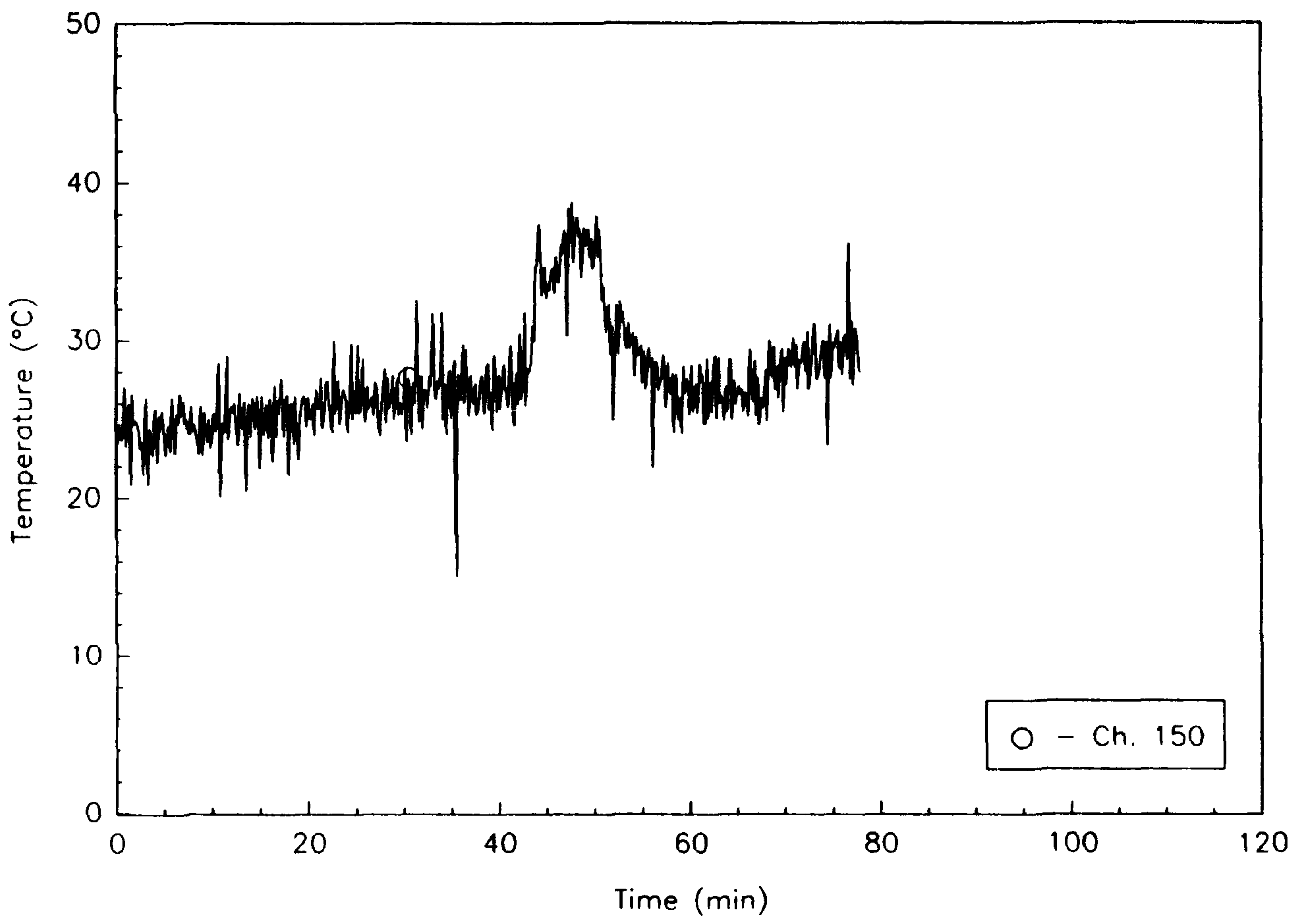

Fig. B73 - Air temperature at 2-9-0 264.2 cm. (104 in.) above the deck

FD_F3

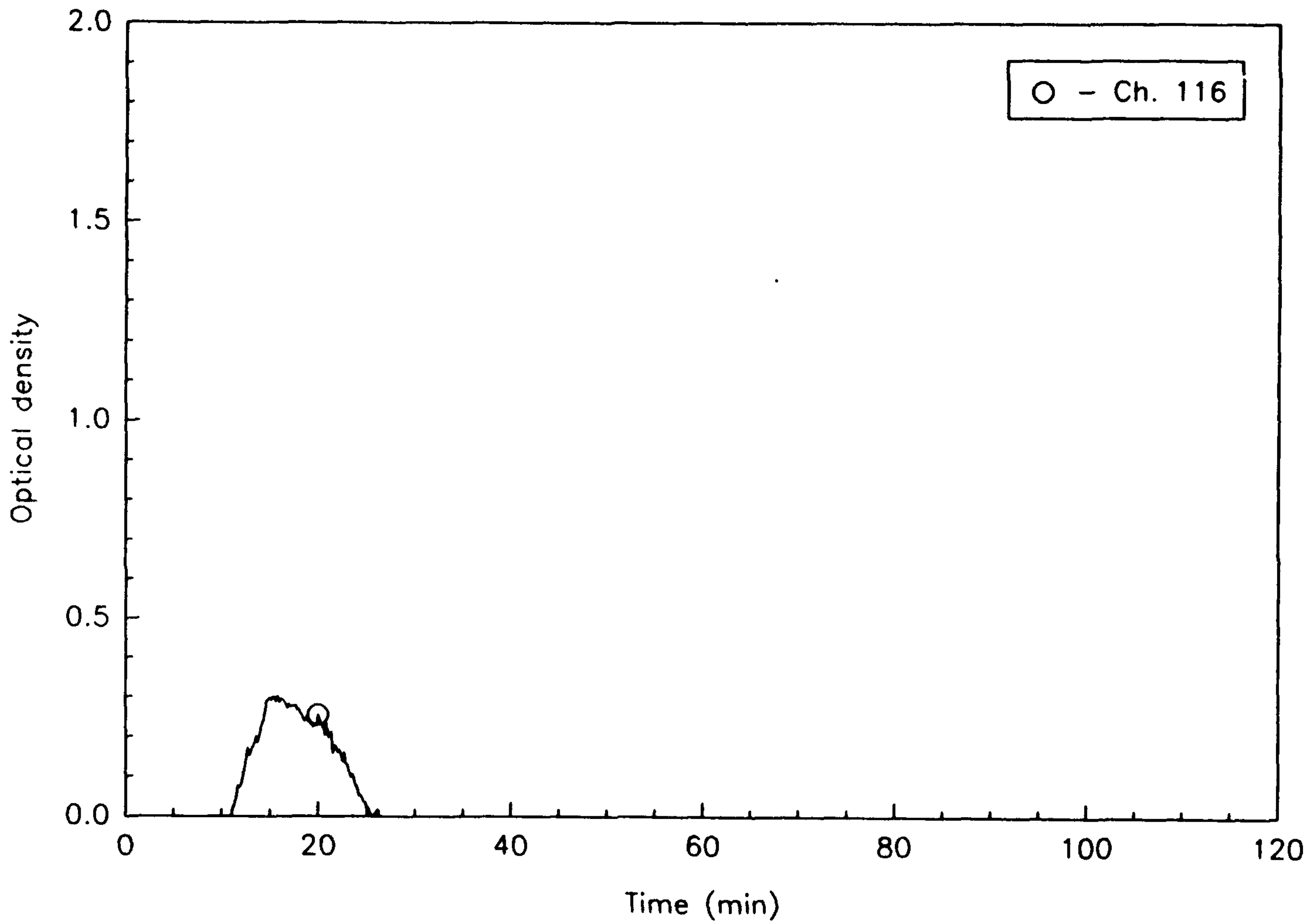

Fig. B74 – Optical density at 1–18–1 in the starboard passageway 152.4 cm. (60 in) above the deck

FD_F11

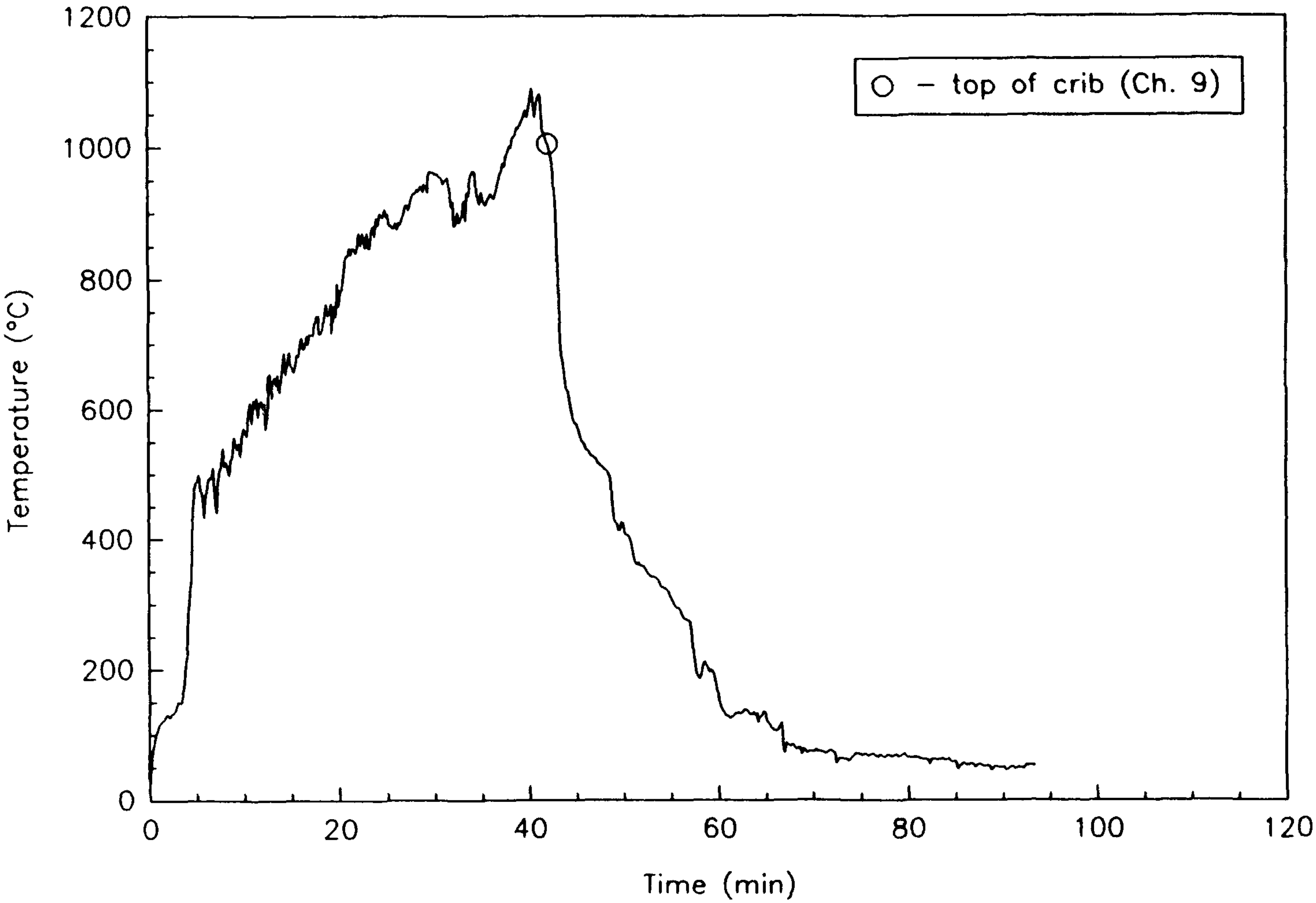

Fig. B75 – Crib #2 temperature at 3-17-2

FD_F11

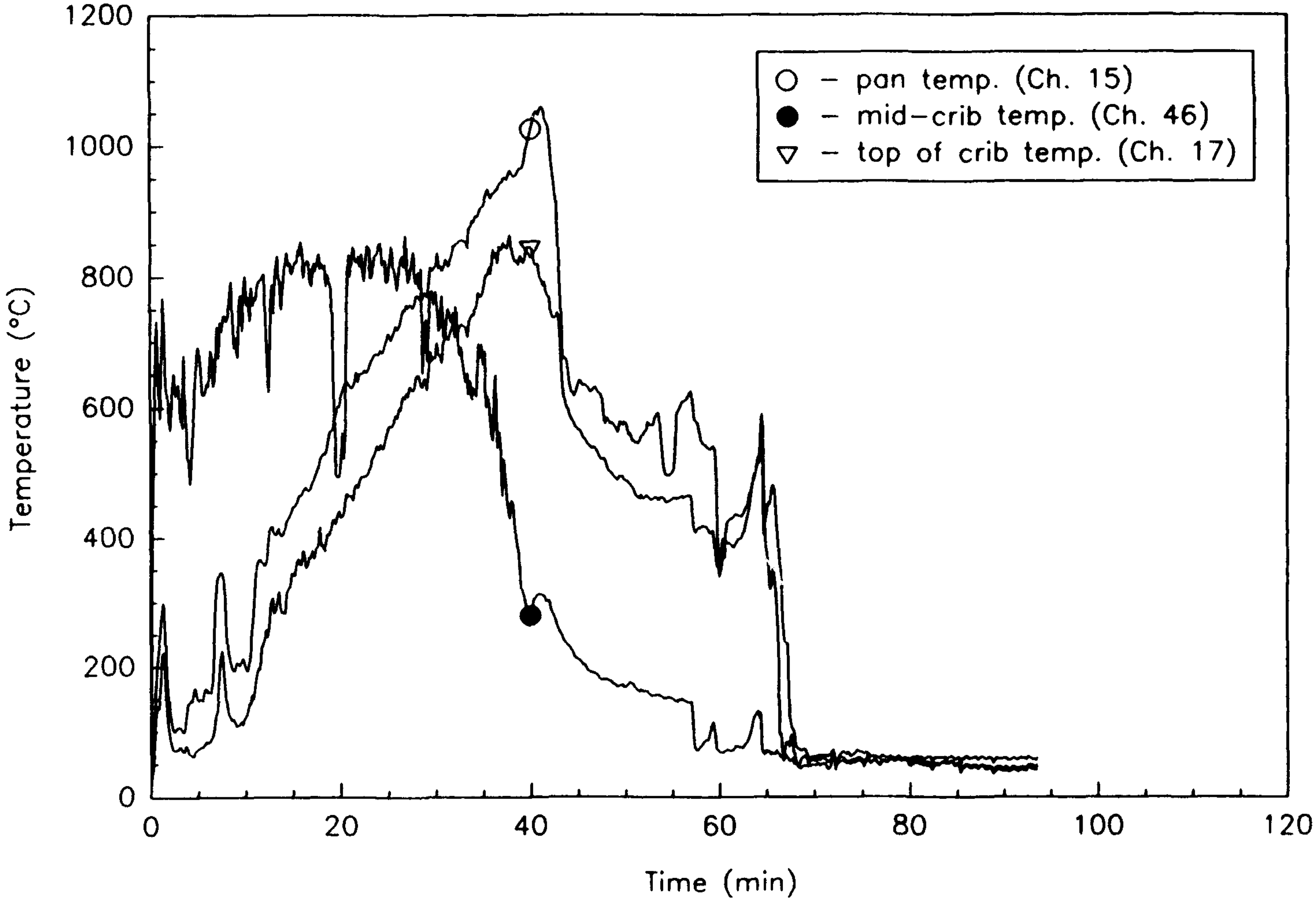

Fig. B76 – Crib #1 temperatures at 3–17–1

FD_F11

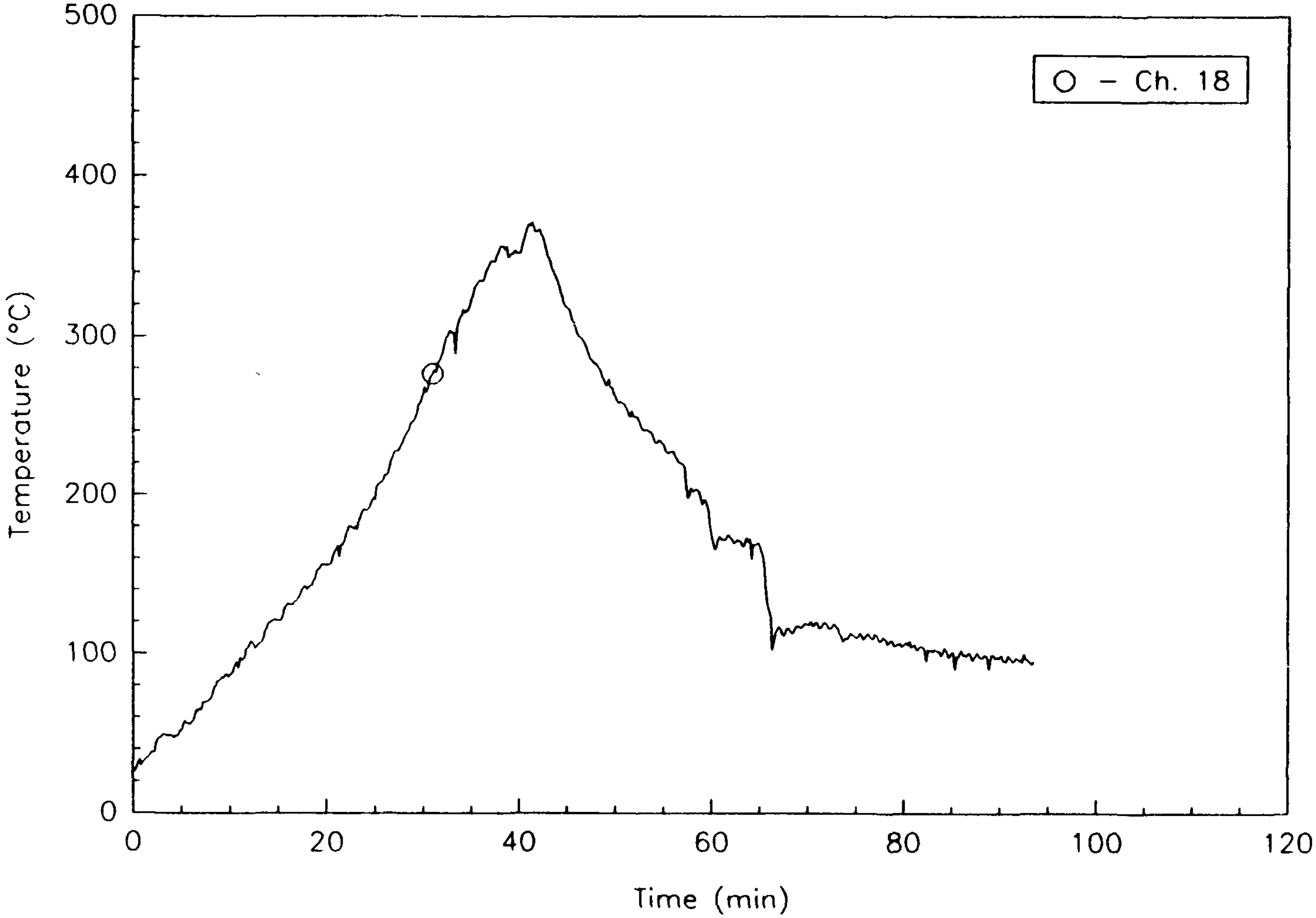

Fig. B77 - Deck temperature at 3-17-1

FD_F11

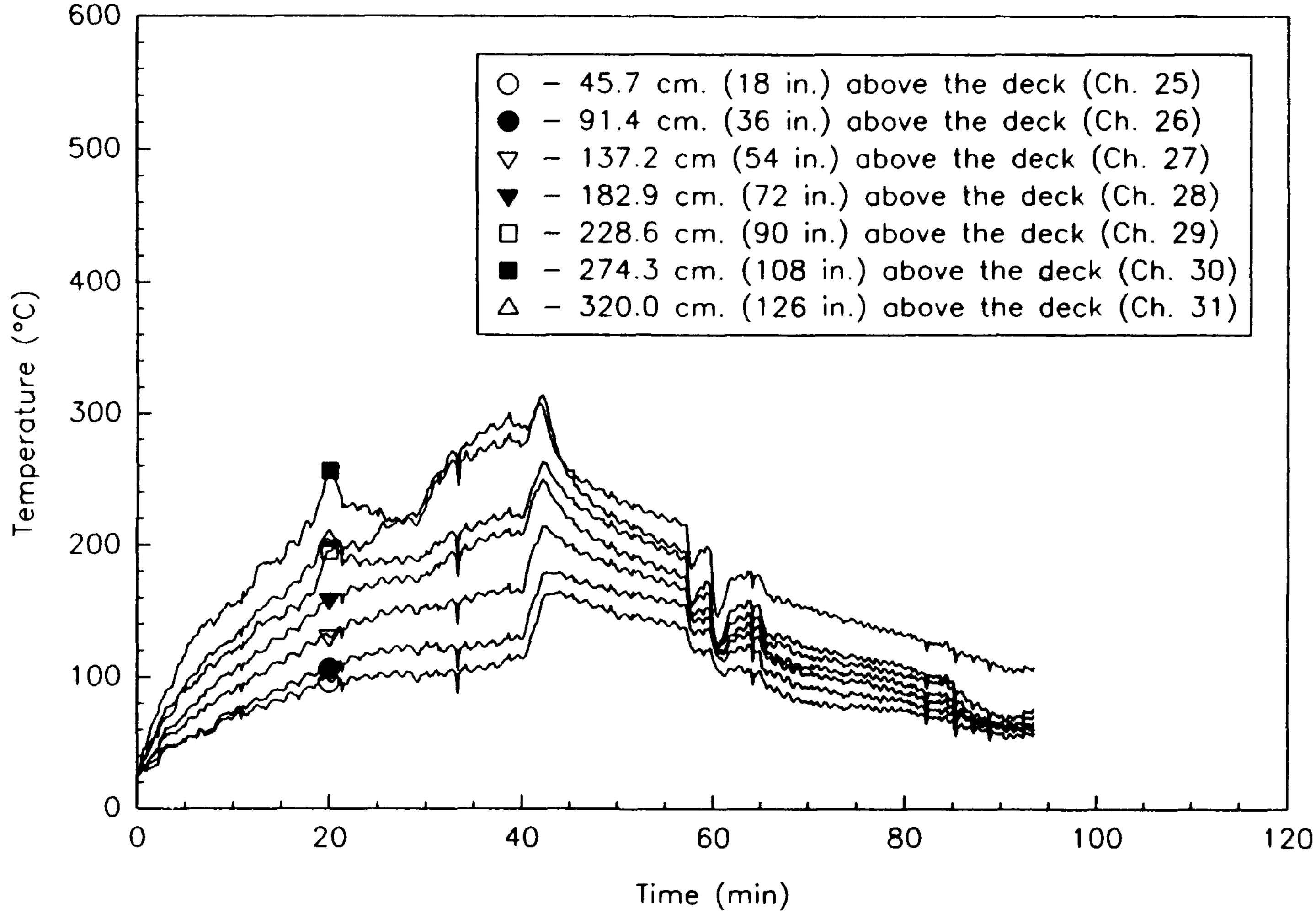

Fig. B78 – Temperature string at 3–20–2

FD_F11

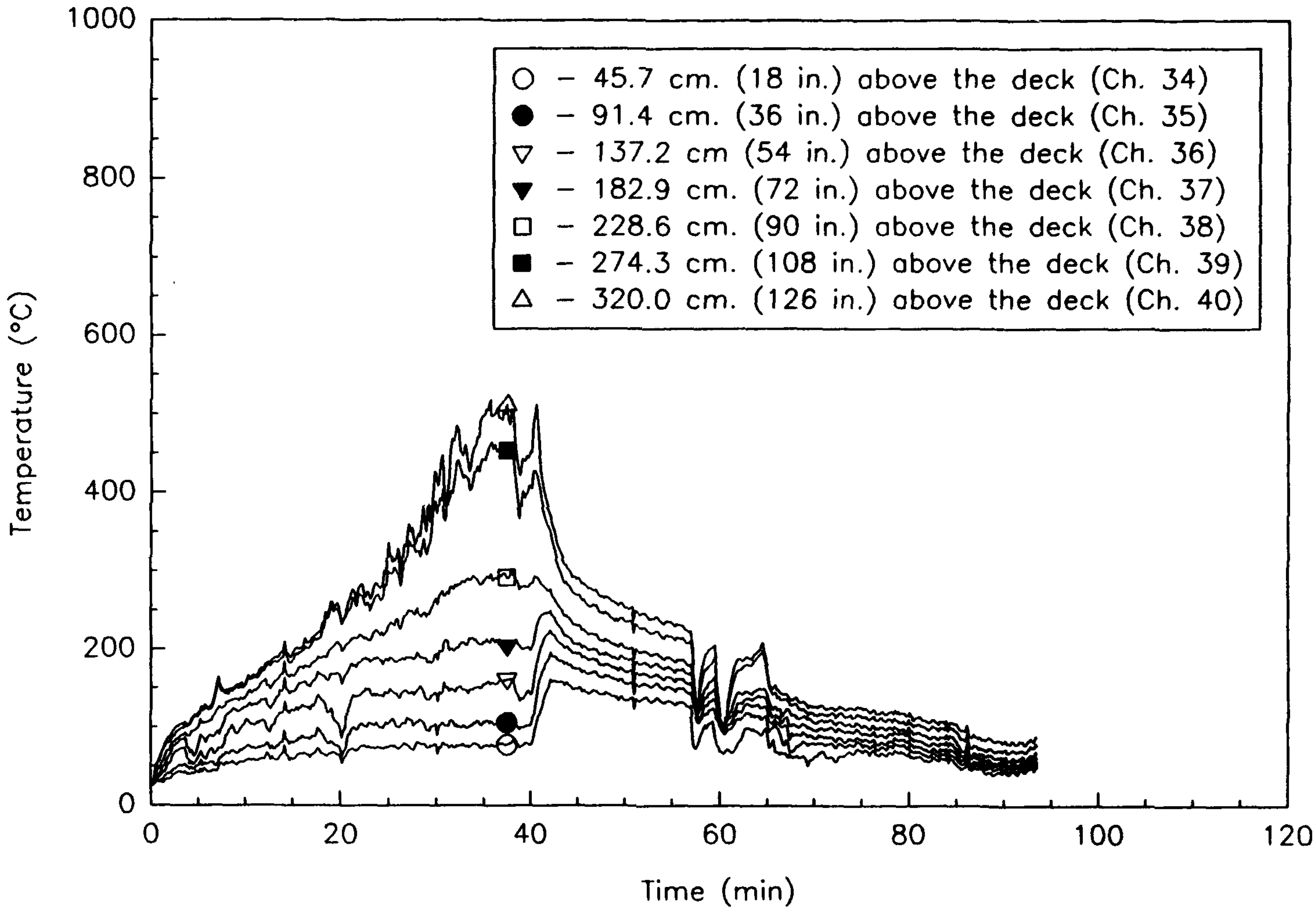

Fig. B79 – Temperature string at 3–20–1

FD_F11

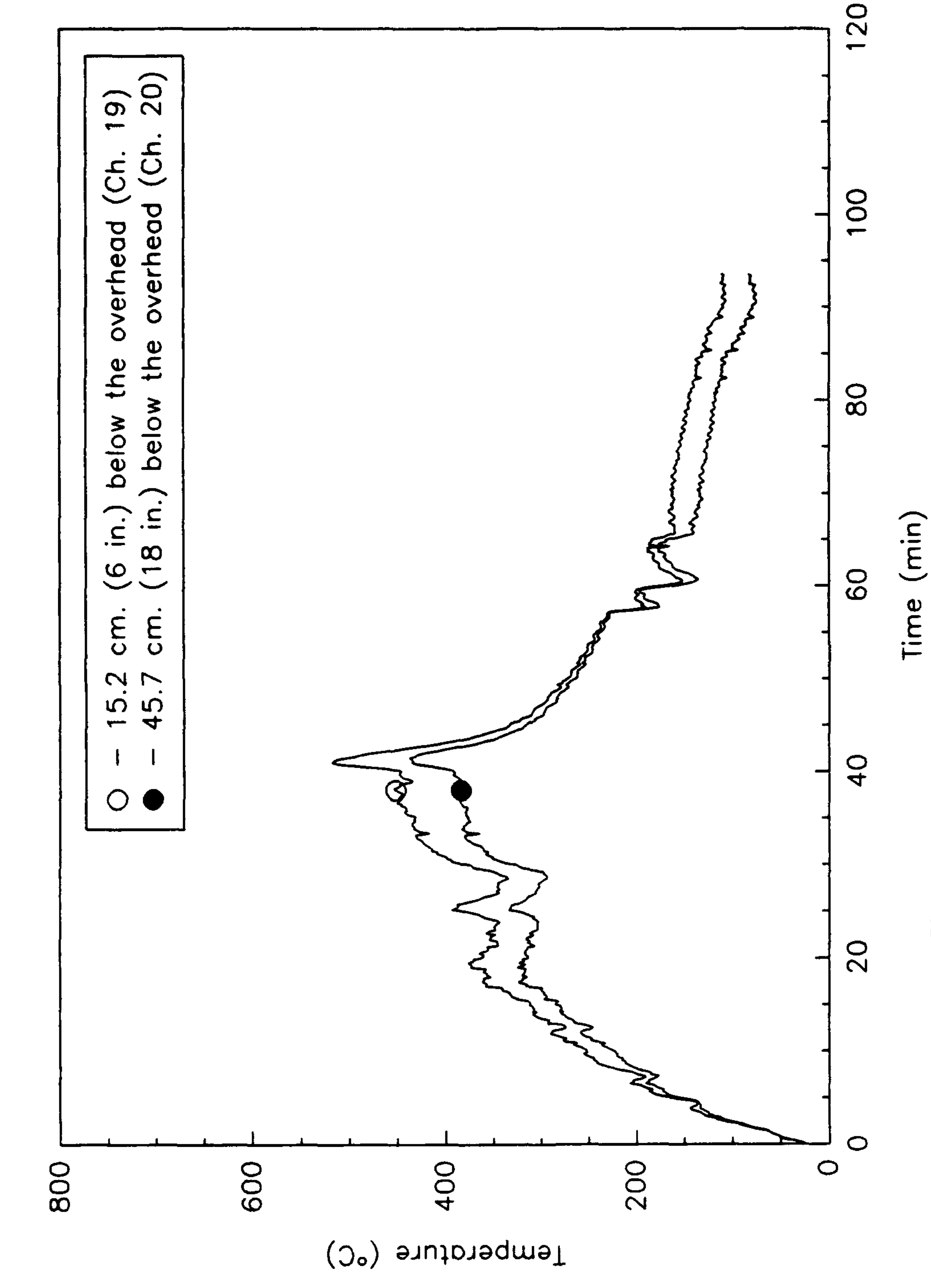

Fig. B80 – Overhead temperatures at 3–17–2

FD_F11

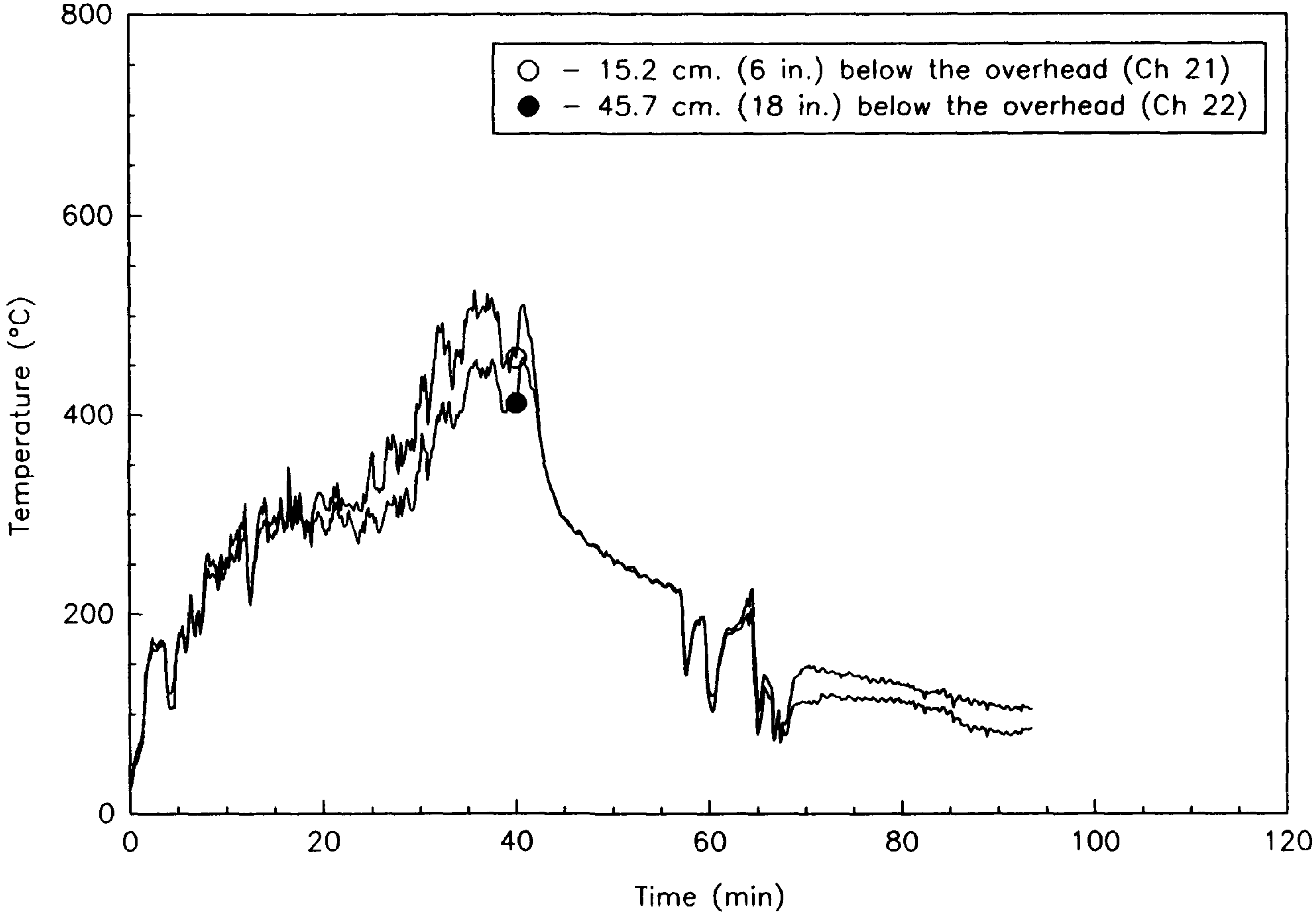

Fig. B81 – Overhead temperatures at 3–17–1

FD_F11

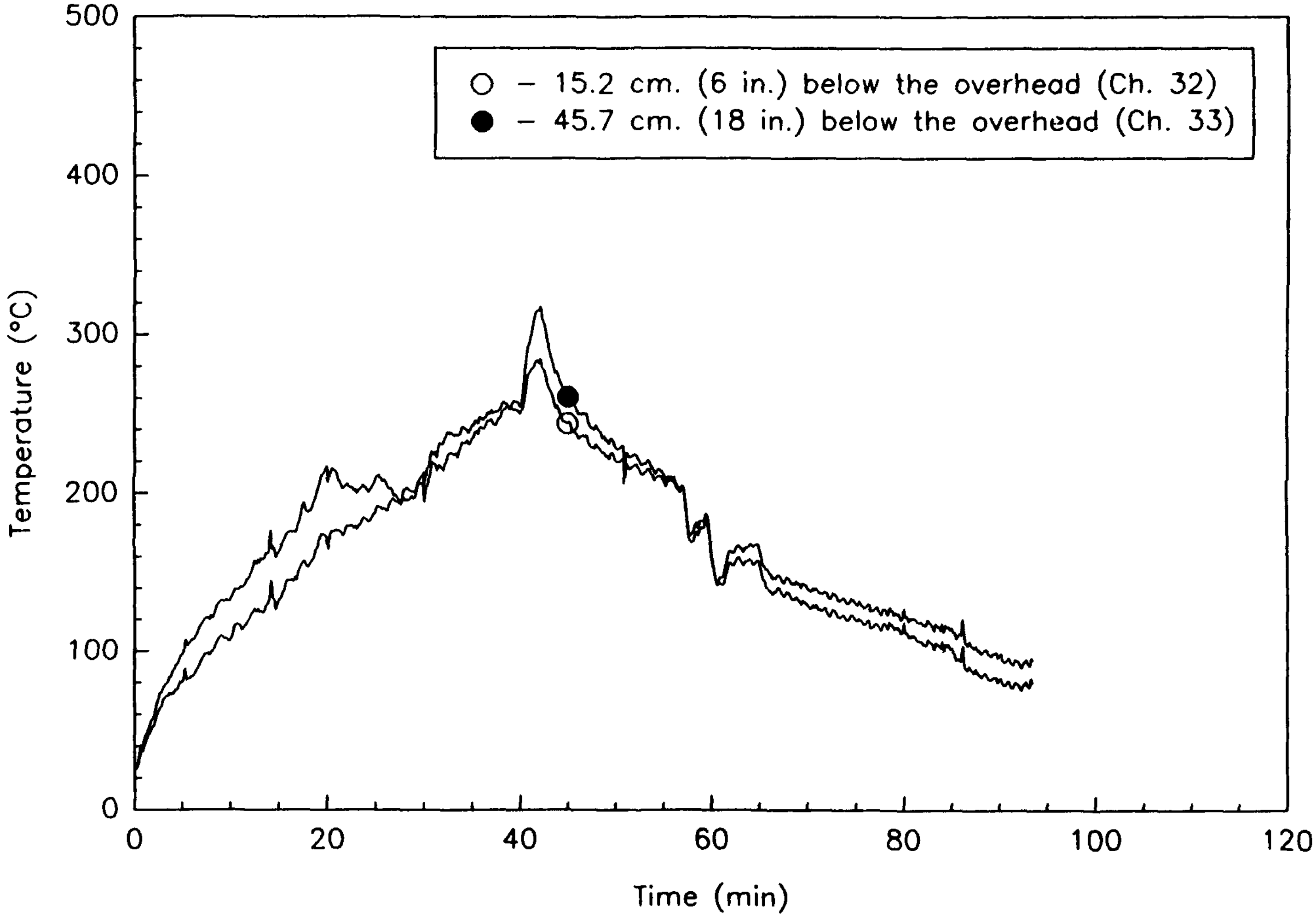

Fig. B82 – Overhead temperatures at 3–21–2

FD_F11

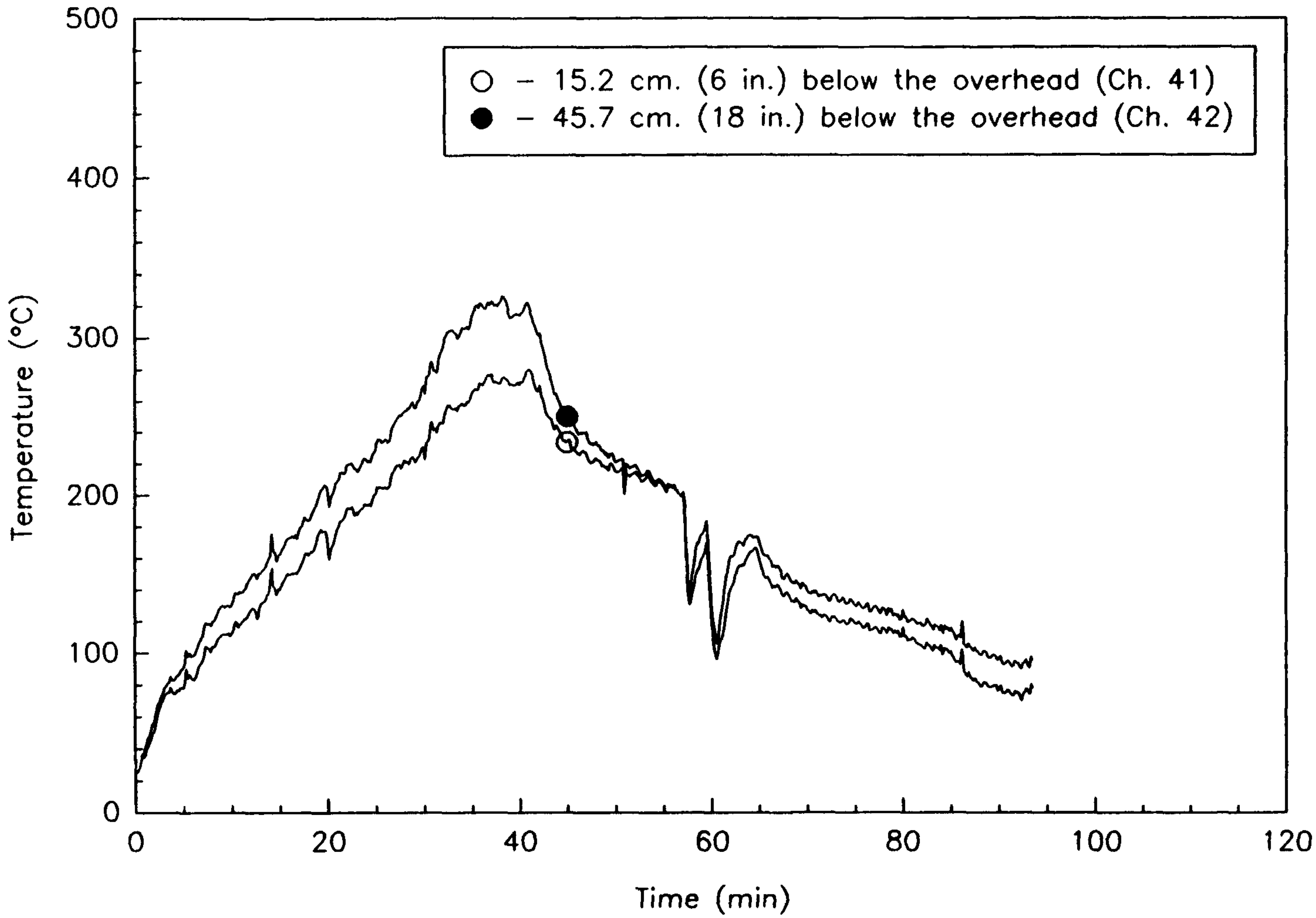

Fig. B83 – Overhead temperatures at 3–21–1

FD_F11

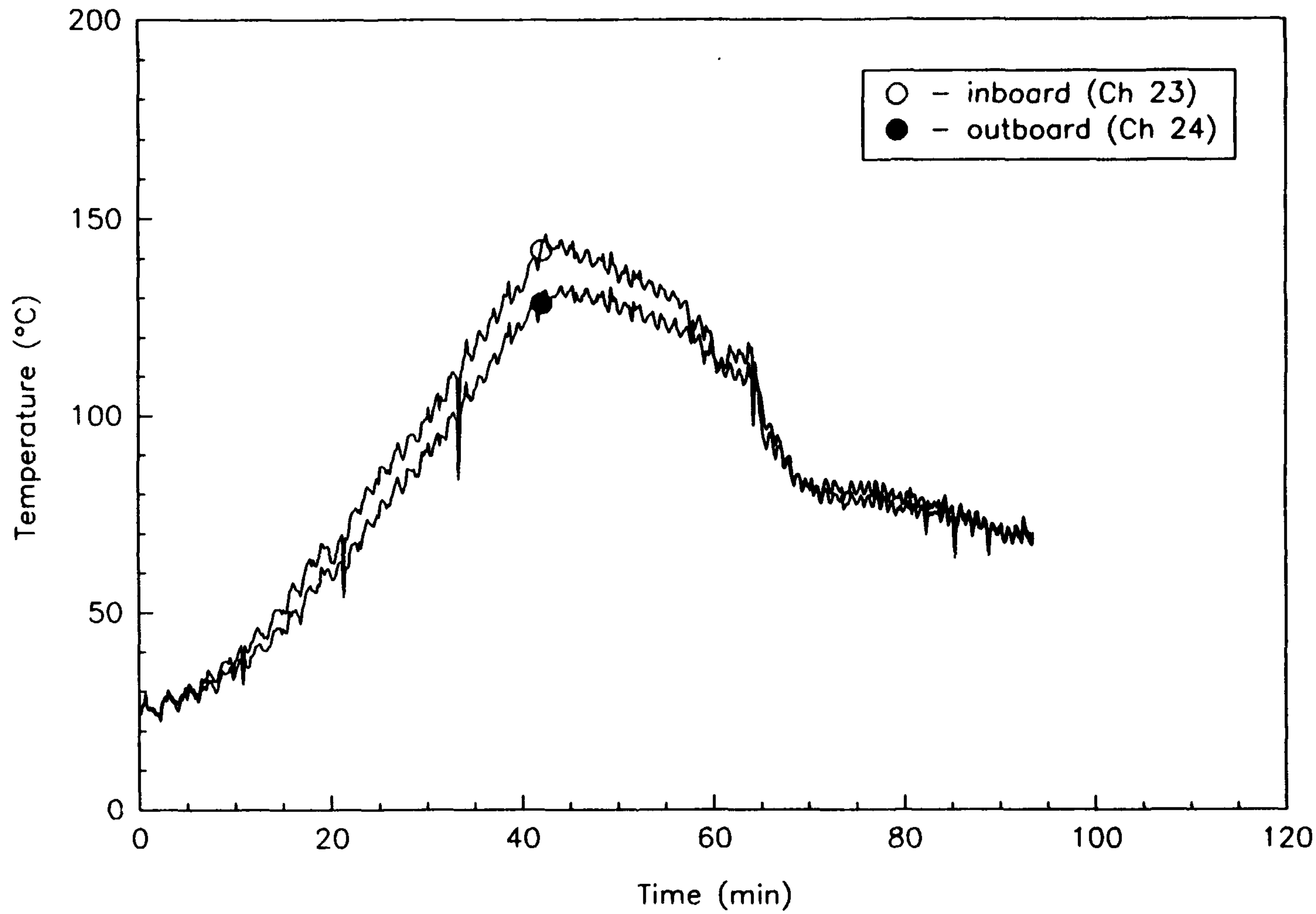

Fig. B84 - Bulkhead temperatures at 3-17-1 152.4 cm. (60 in.) above the deck

FD_F11

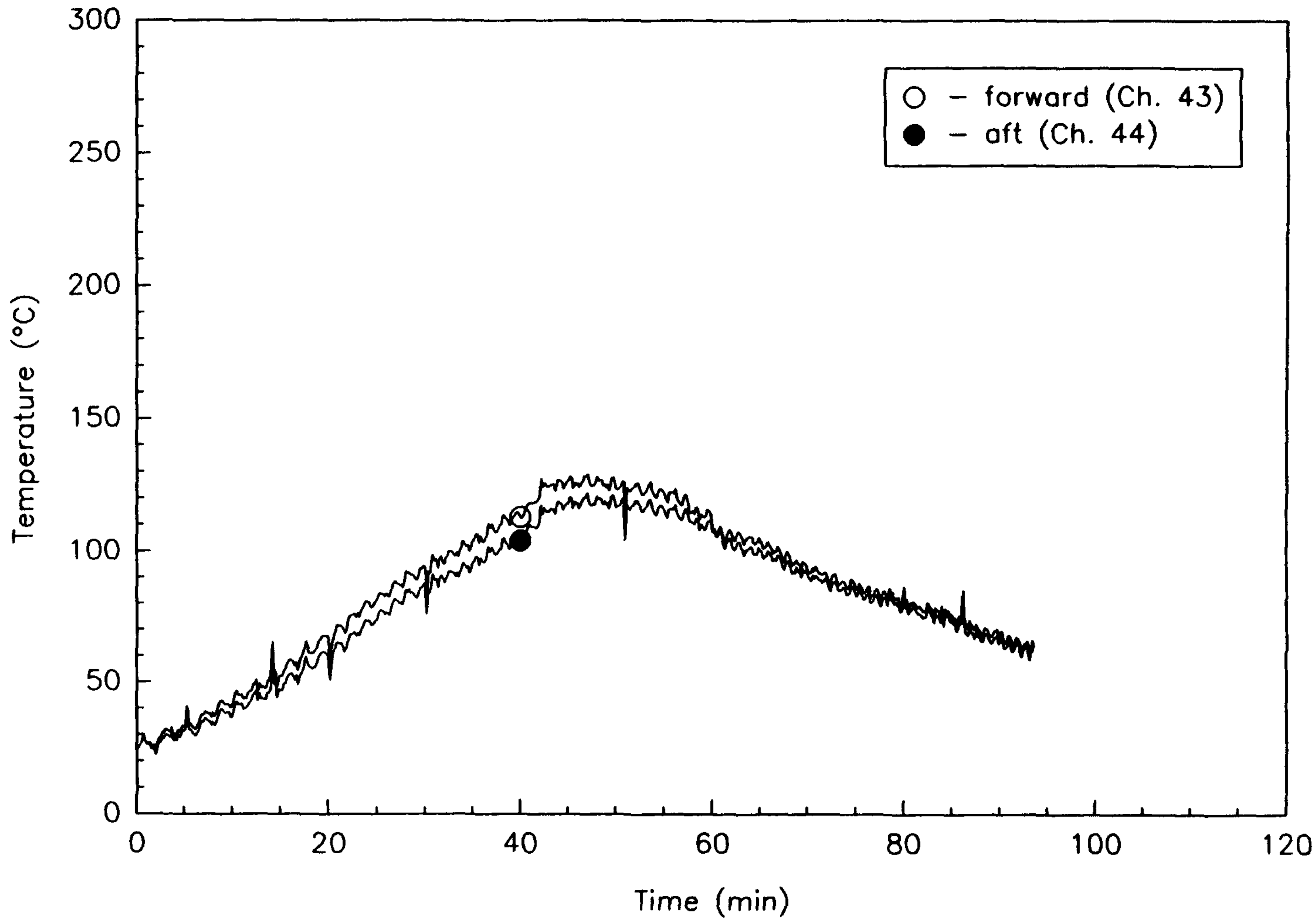

Fig. B85 – Bulkhead temperature at 3-22-0 152.4 cm. (60 in.) above the deck

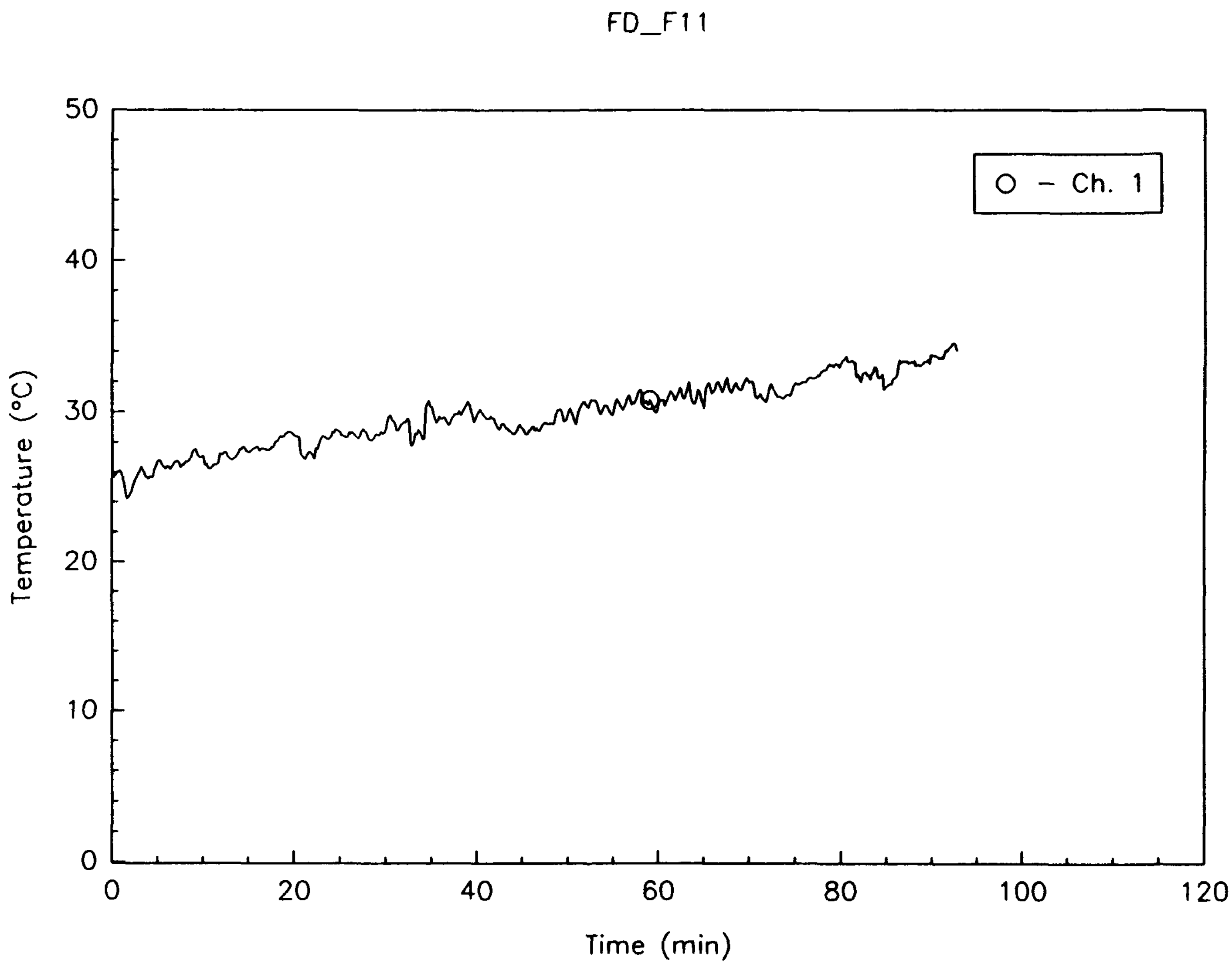

Fig. B86 – Air temperature at 3–16–2 152.4 cm. (60 in.) above the deck (above Emergency Diesel Fire Pump)

FD_F11

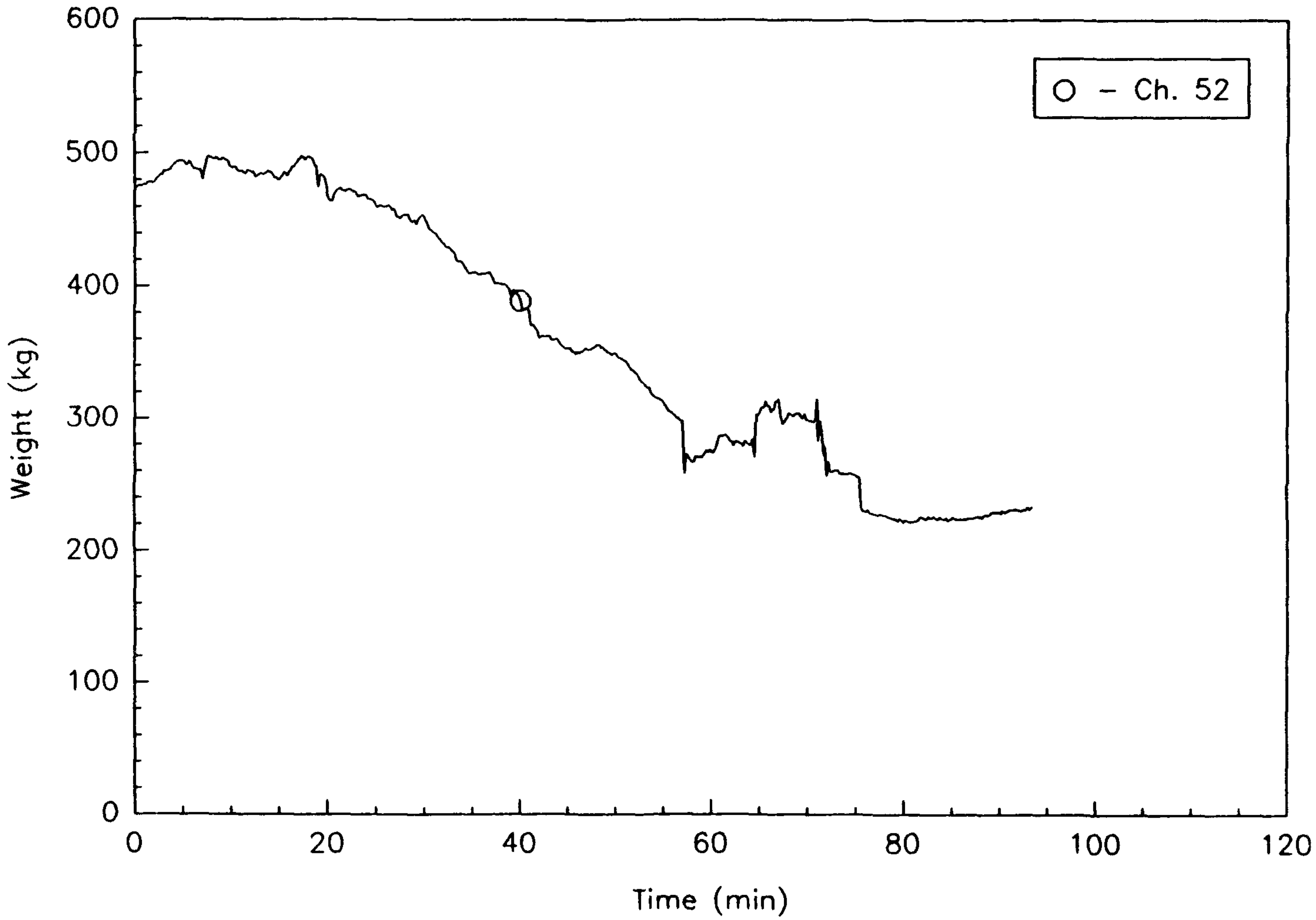

Fig. B87 – Crib #1 weight at 3–17–1

FD_F11

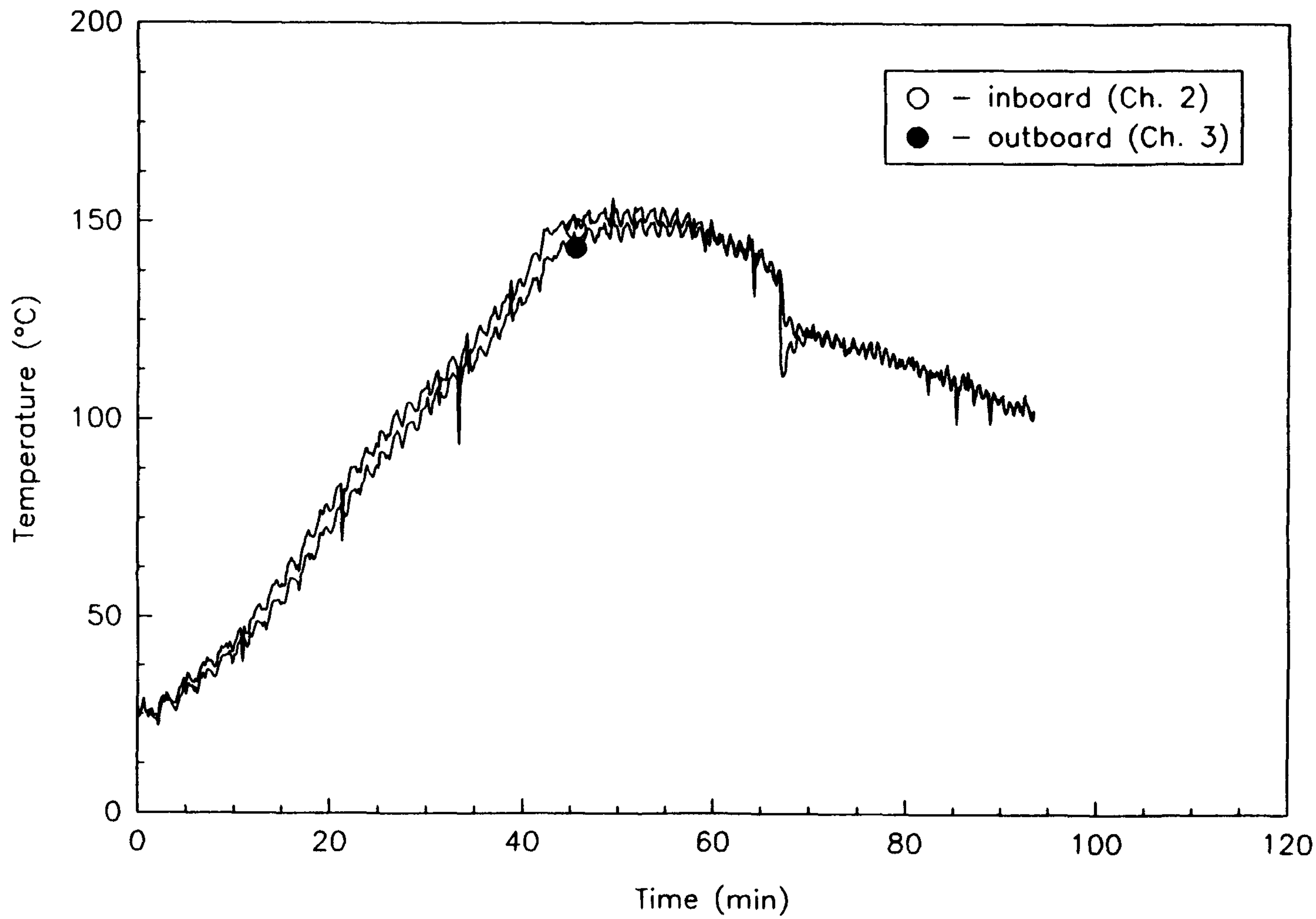

Fig. B88 – Bulkhead temperatures at 3–16–2 152.4 cm. (60 in.) above the deck

FD_F11

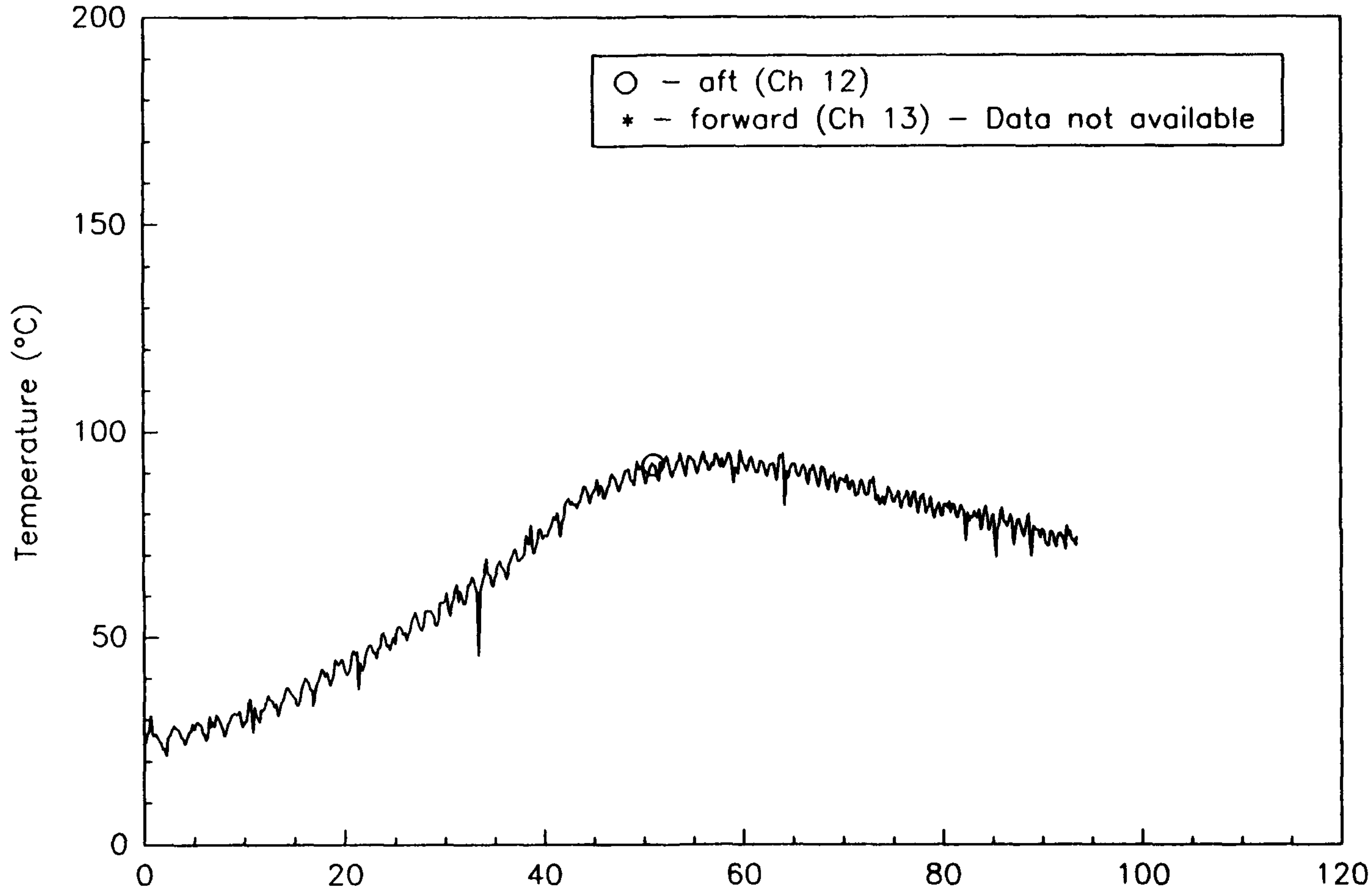

Fig. B89 – Bulkhead temperatures at 3–15–0 152.4 cm. (60 in.) above the deck

FD_F11

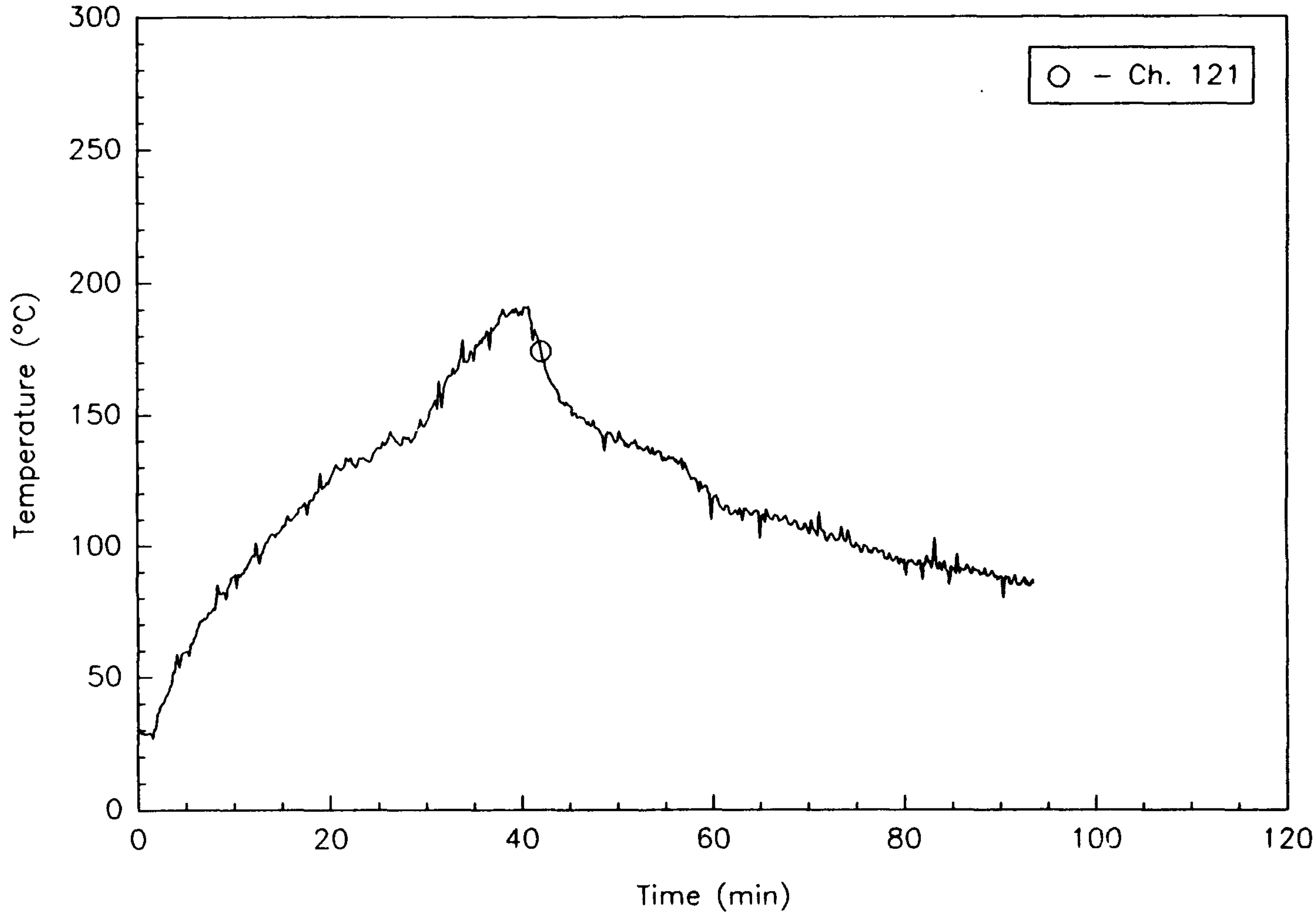

Fig. B90 – Air temperature at 2–16–1 in Crew Living 1
304.8 cm. (120 in.) above the deck

FD_F11

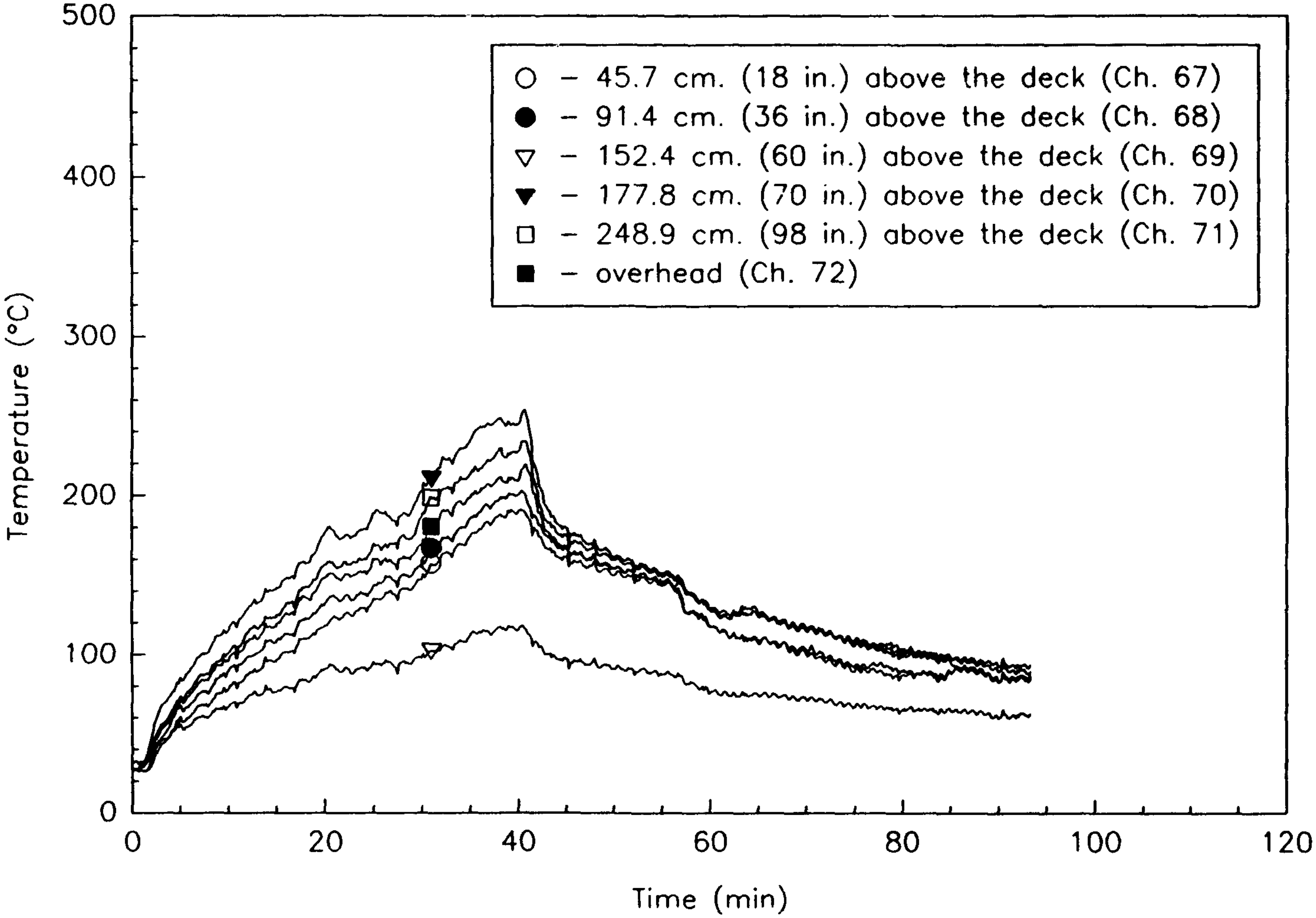

Fig. B91 – Temperature string at 2–20–2

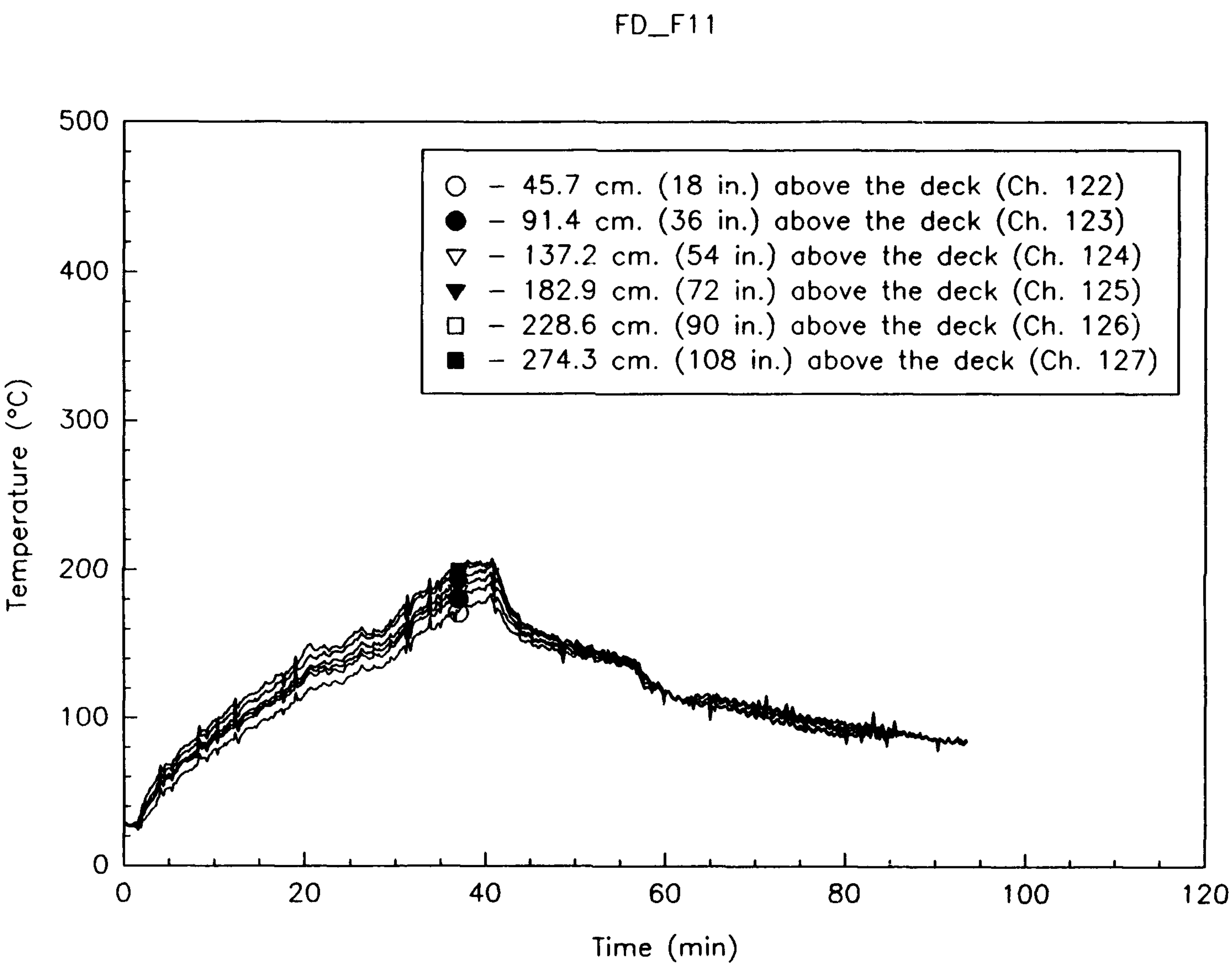

Fig. B92 – Temperature string at 2–21–1 in Crew Living 1

FD_F11

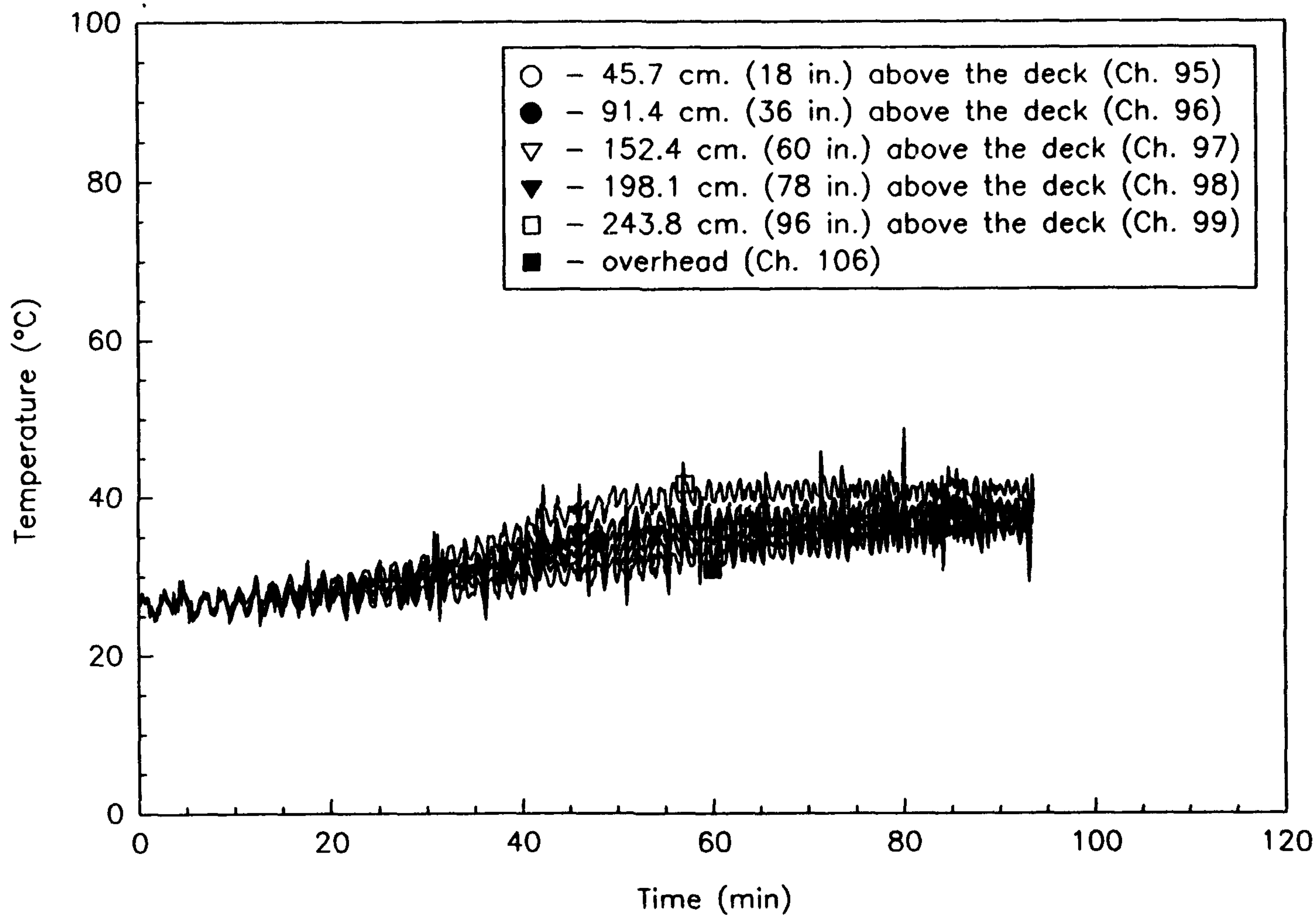

Fig. B93 – Temperature string at 2-25-2 in CIC AFT

FD_F11

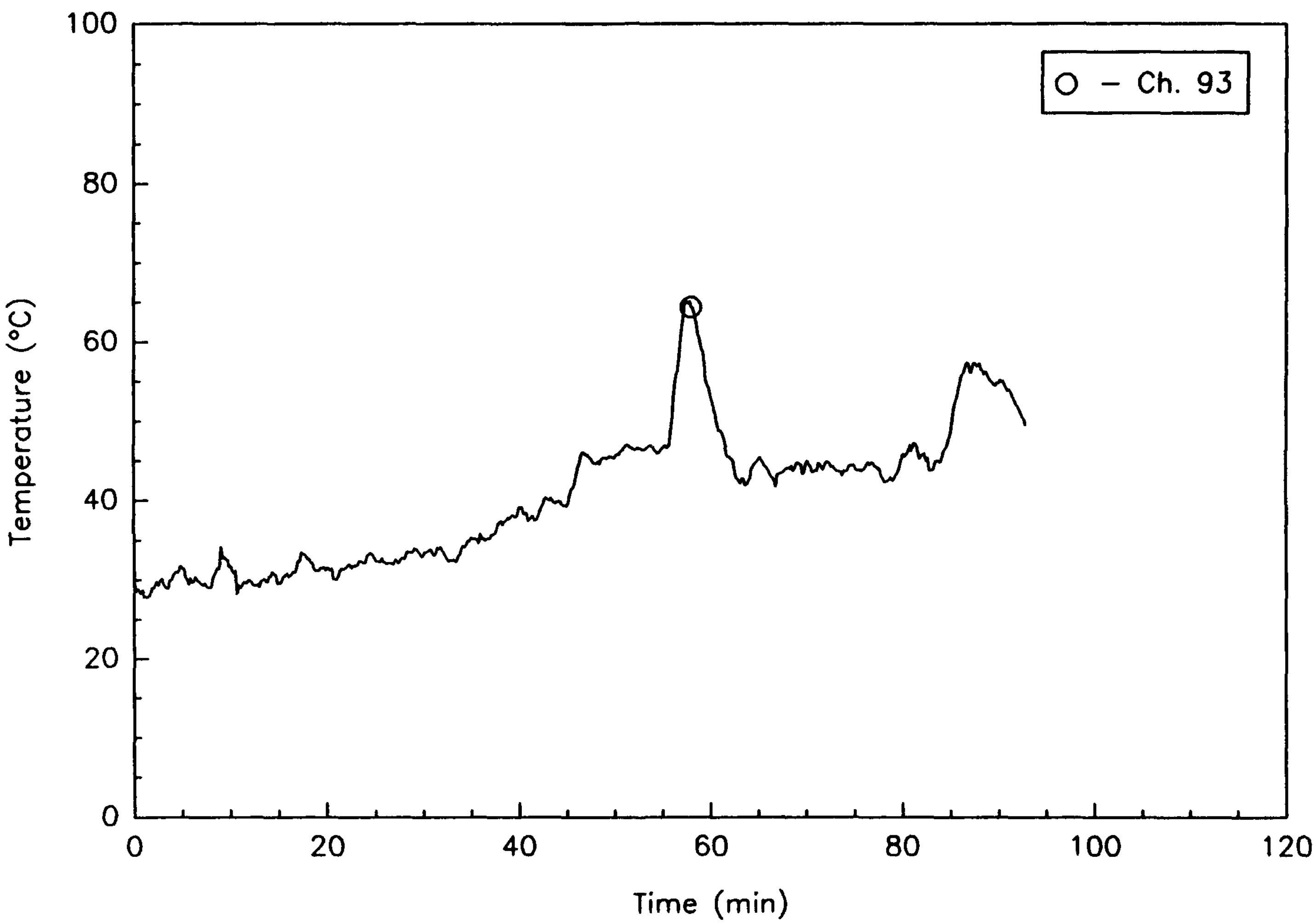

Fig. B94 – Lintel temperature at QAWTD 2–17–1

FD_F11

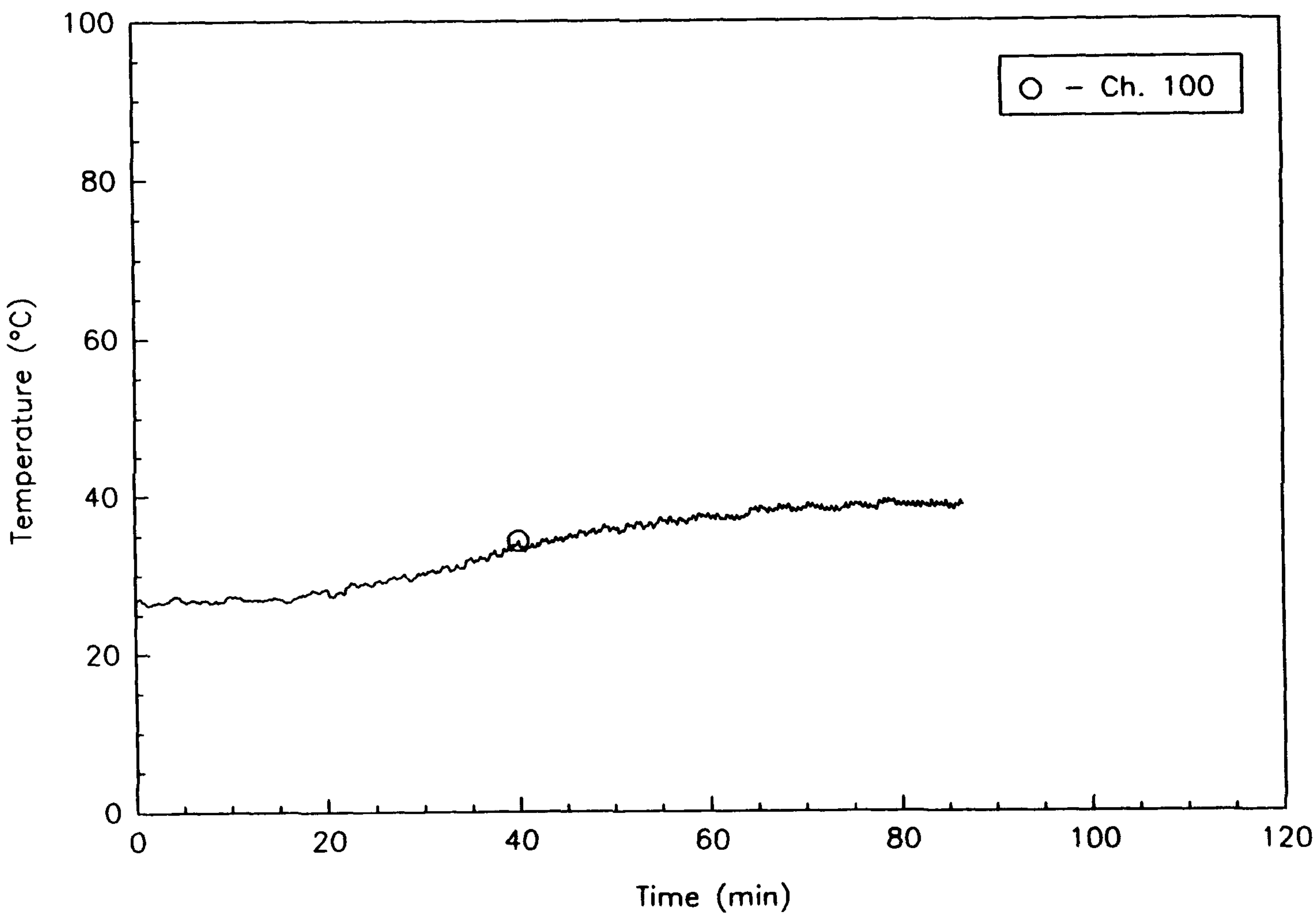

Fig. B95 – Lintel temperature at 2–26–2

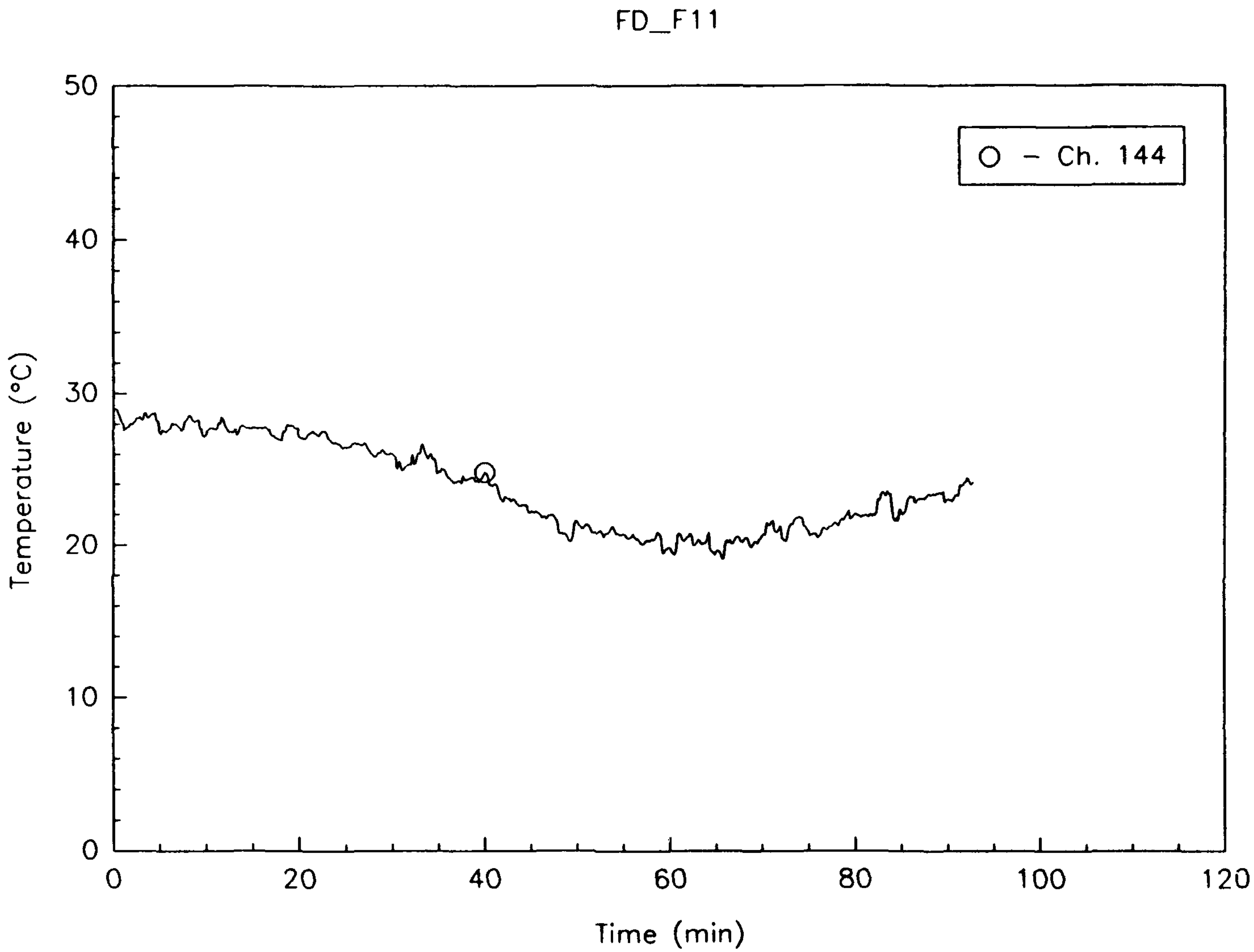

Fig. B96 – Air temperature at 2–17–2 in port passageway
152.4 cm. (60 in.) above the deck

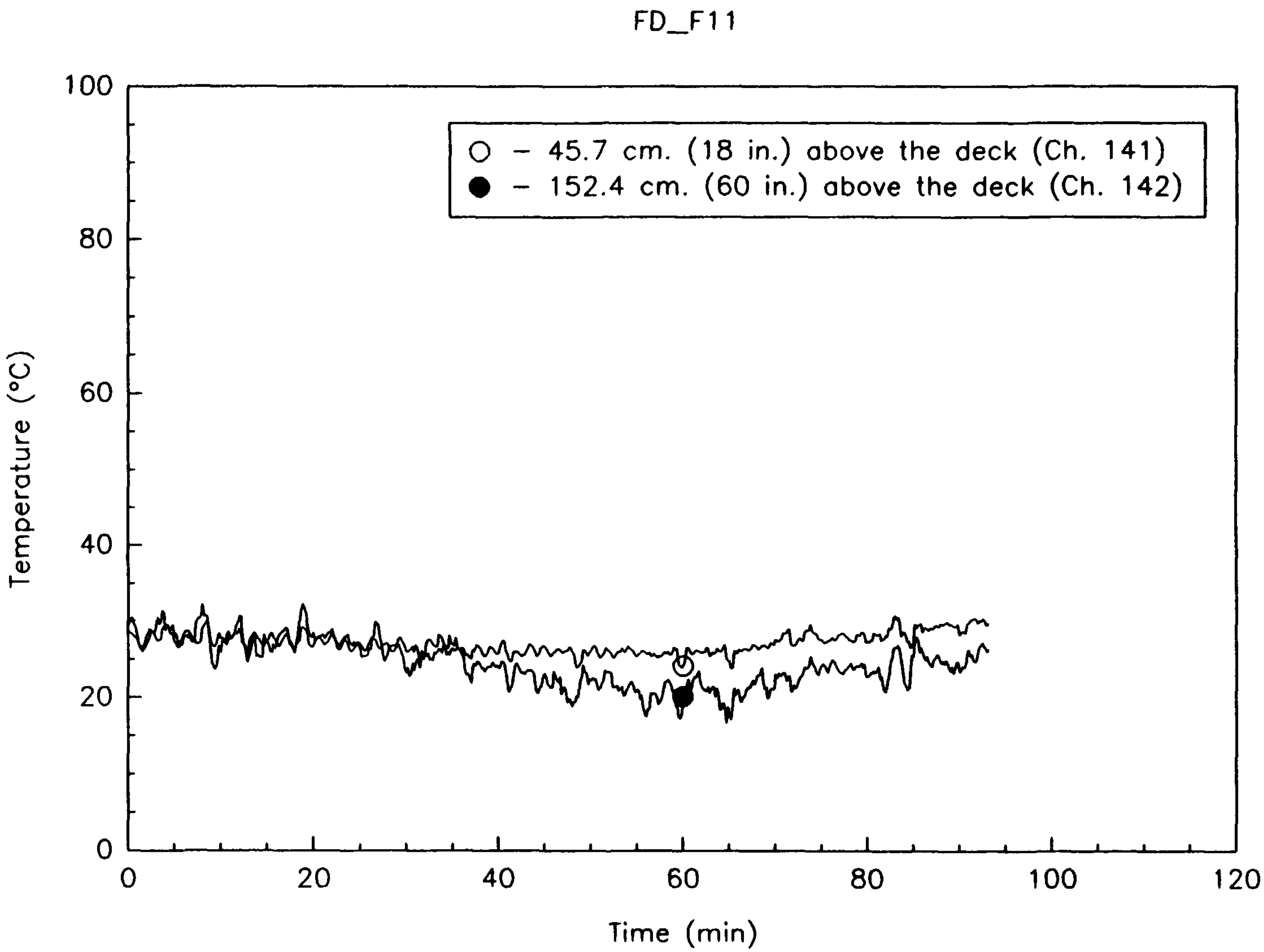

Fig. B97 – Air temperature at 2–19–2 in port passageway

FD_F11

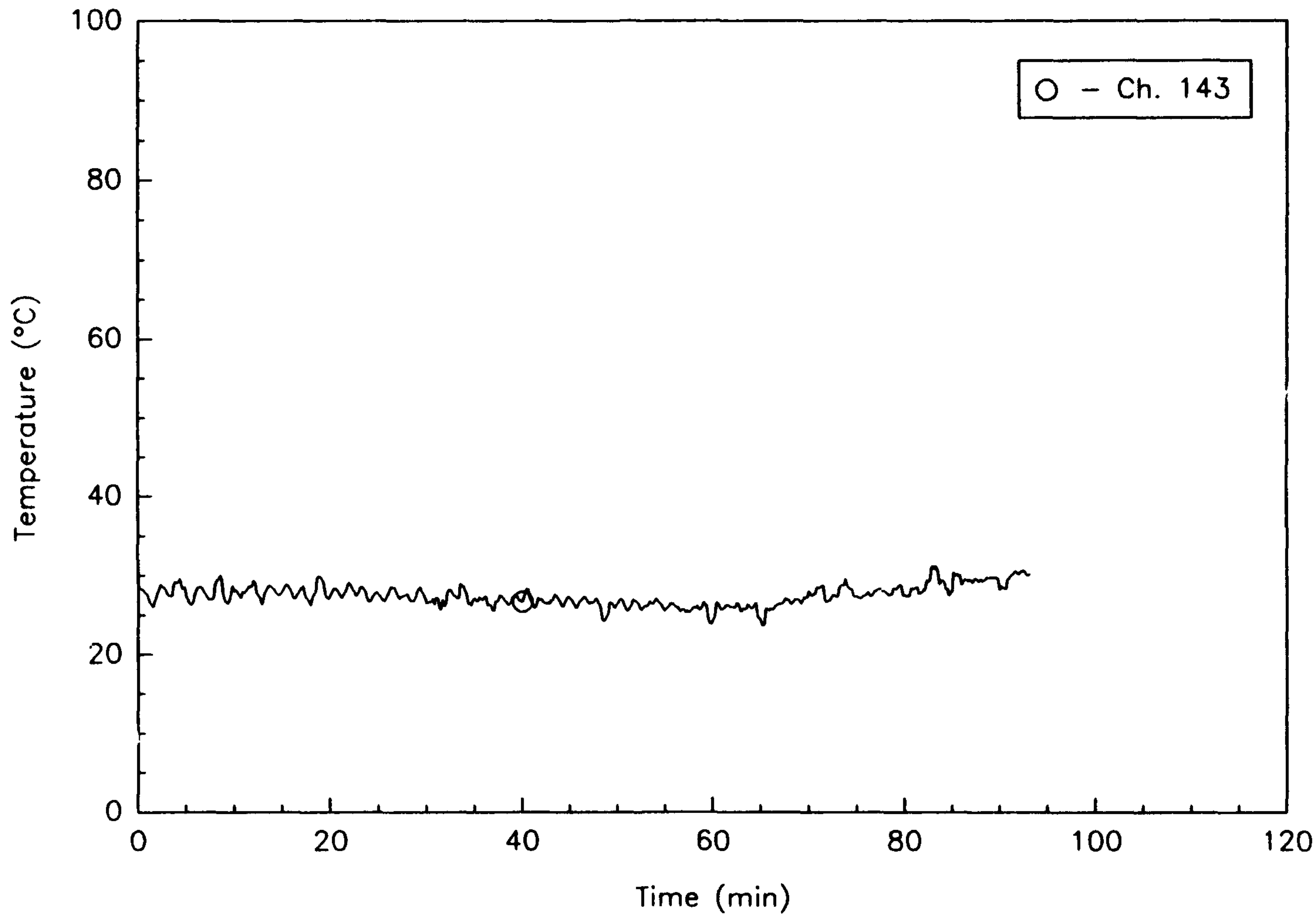

Fig. B98 – Air temperature at 2–23–2 in the port passageway 152.4 cm. (60 in.) above the deck

FD_F11

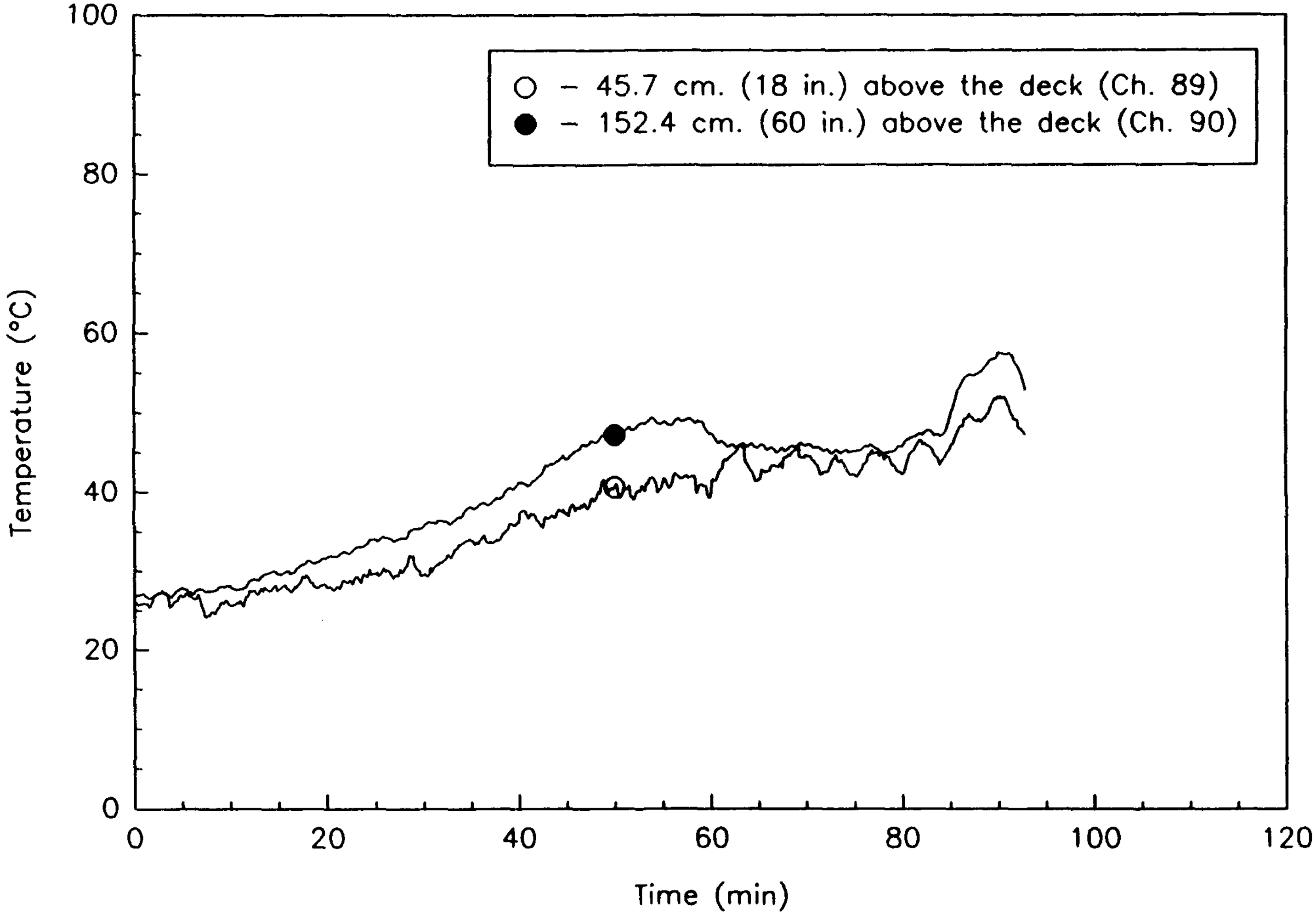

Fig. B99 – Air temperature at 2–18–1 starboard passageway

FD_F11

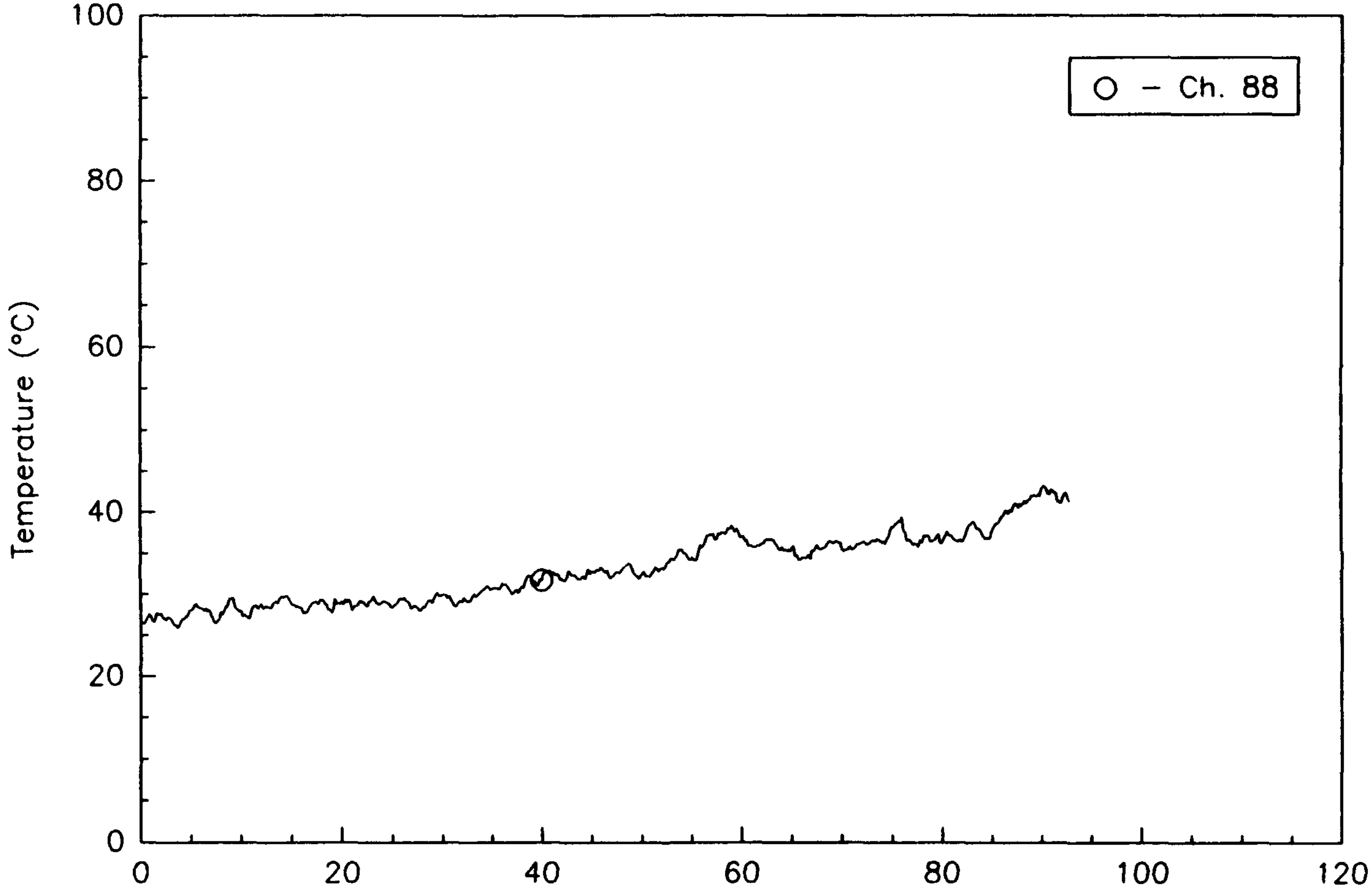

Fig. B100 – Air temperature at 2–23–1 in the starboard passageway 152.4 cm. (60 in.) above the deck

FD_F11

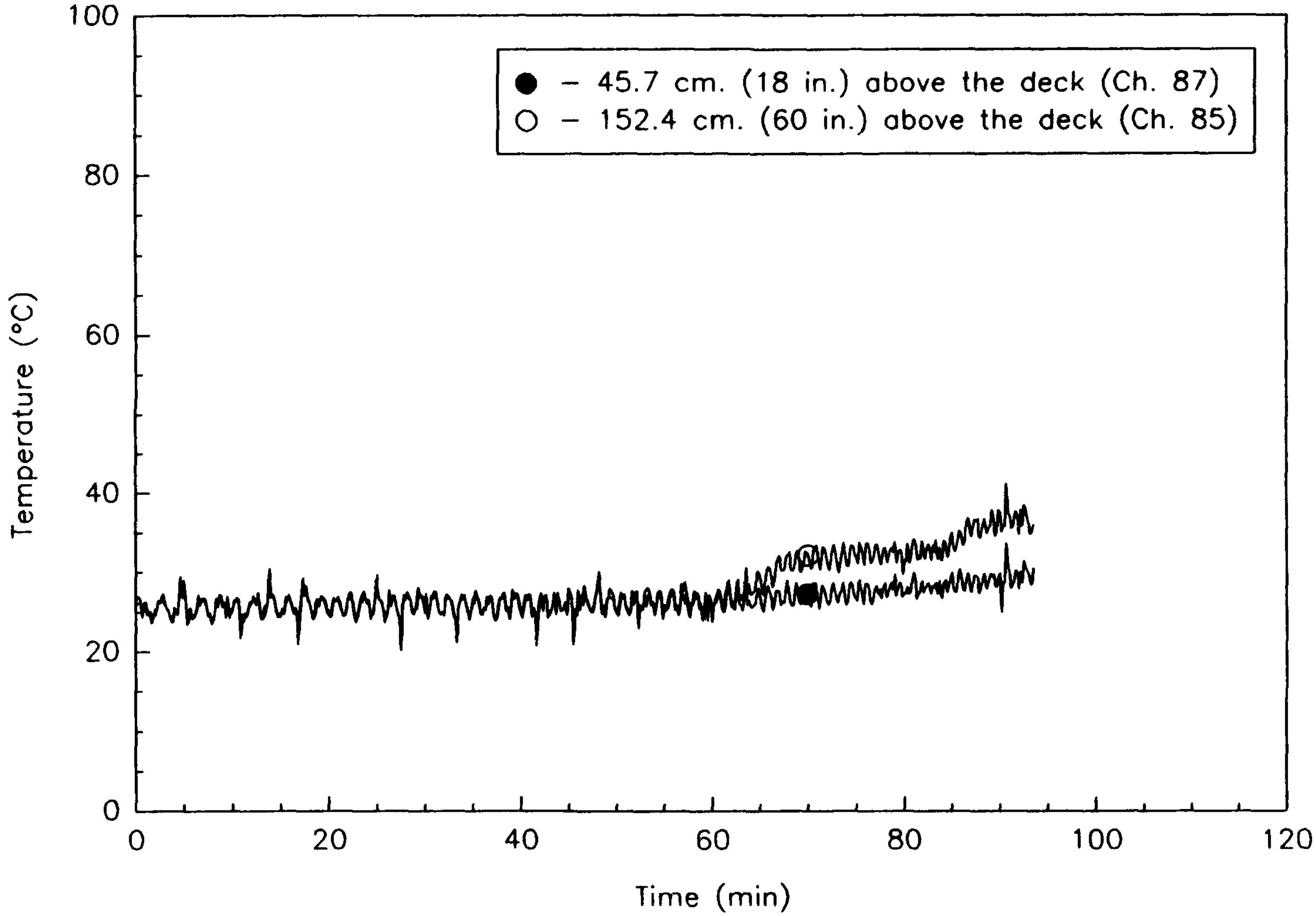

Fig. B101 – Air temperature at 2–24–1 in the starboard passageway

FD_F11

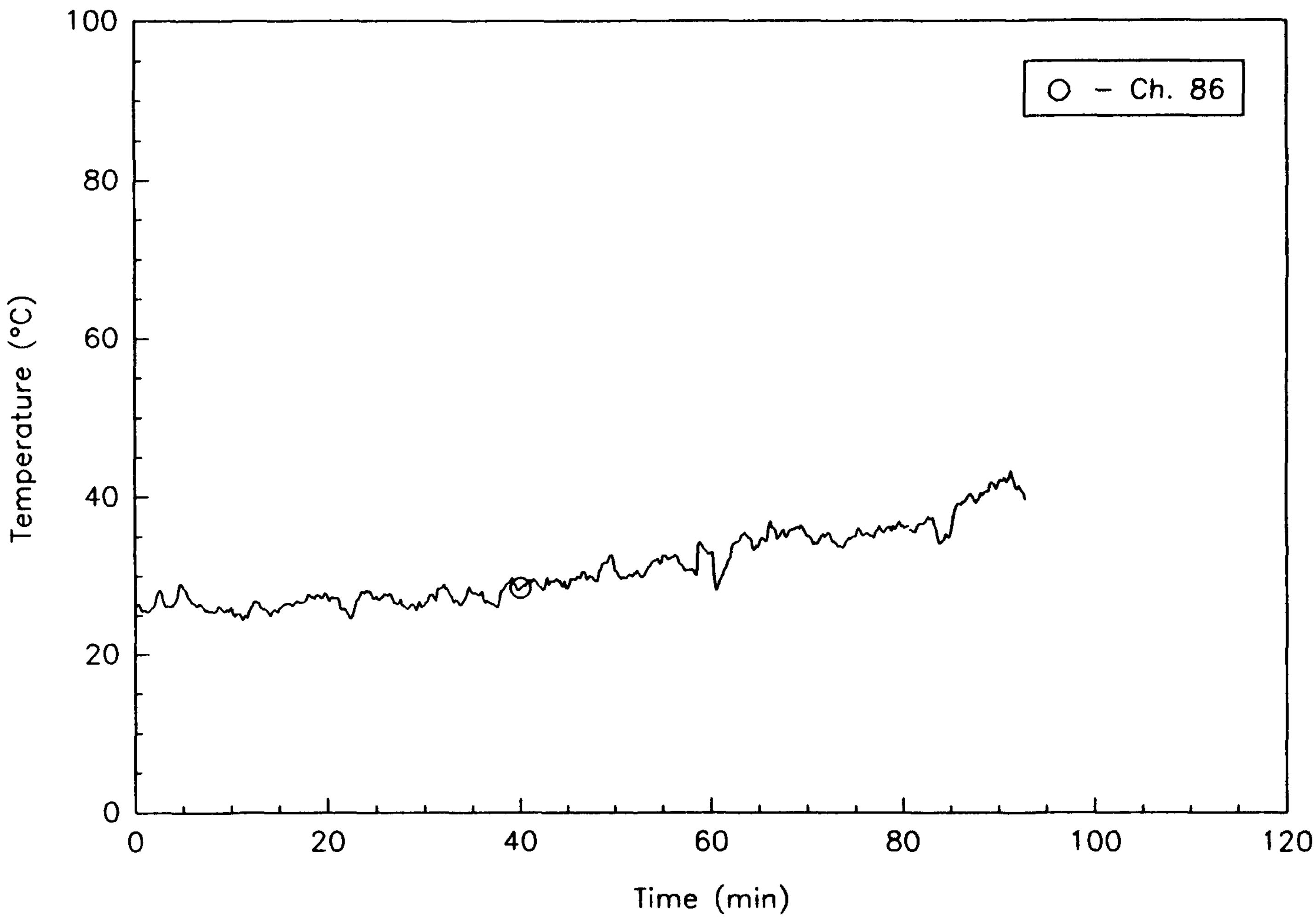

Fig. B102 – Air temperature at 2–25–1 in the starboard passageway 152.4 cm. (60 in.) above the deck

FD_F11

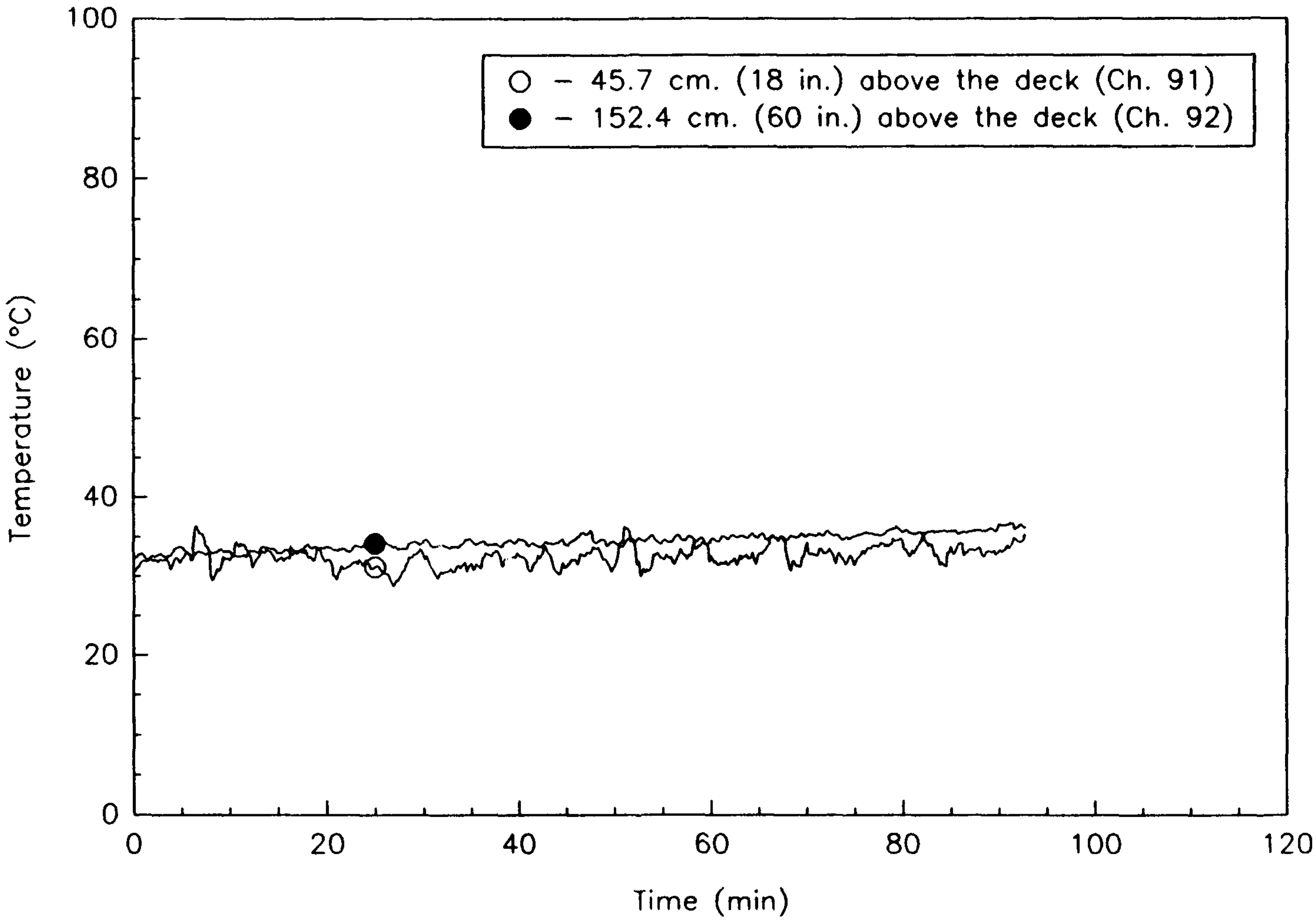

Fig. B103 – Air temperature at 2–9–1 in Repair 2

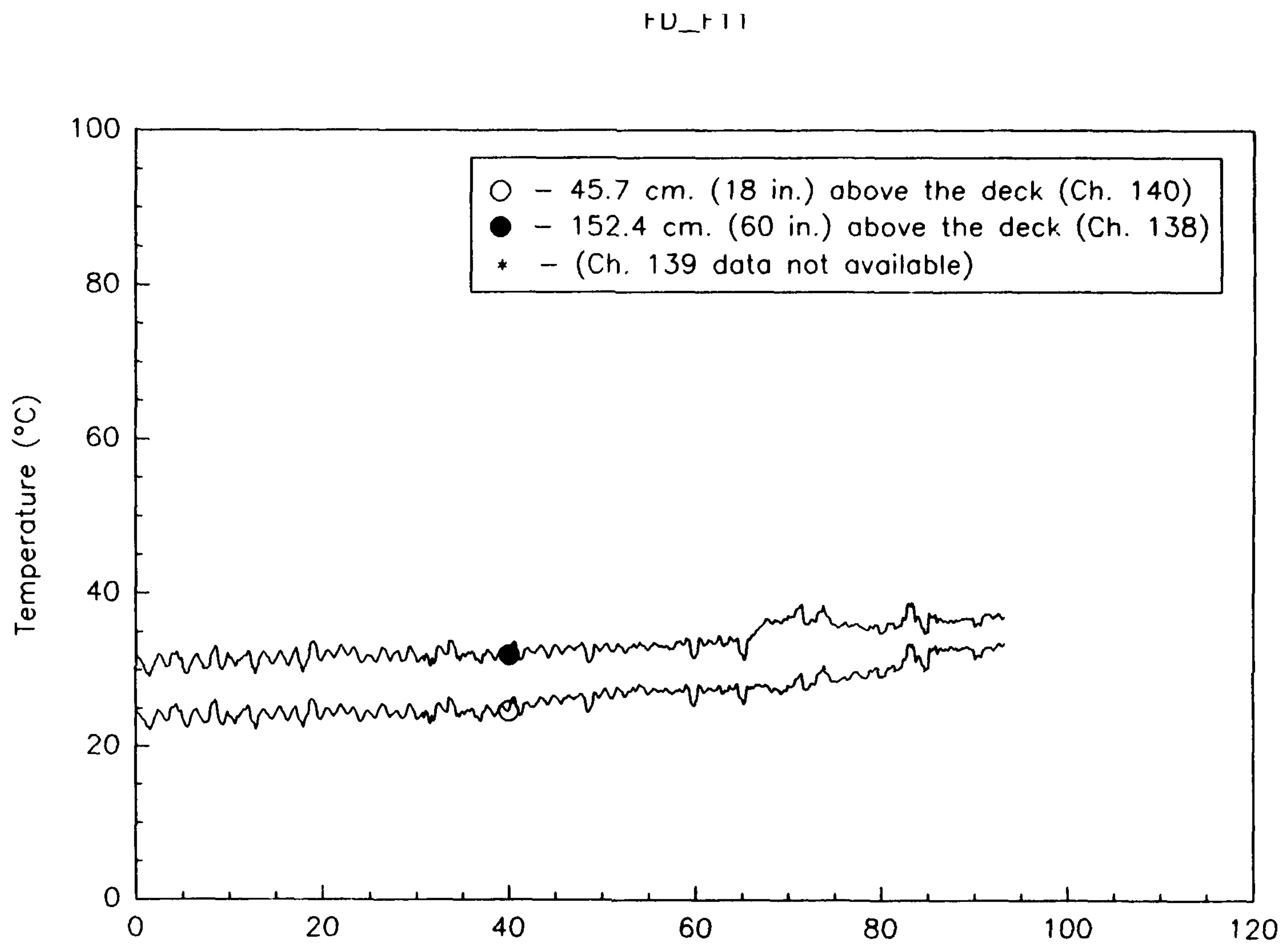

Fig. B104 – Air temperature at 2–13–2 athwartship passageway

FD_F11

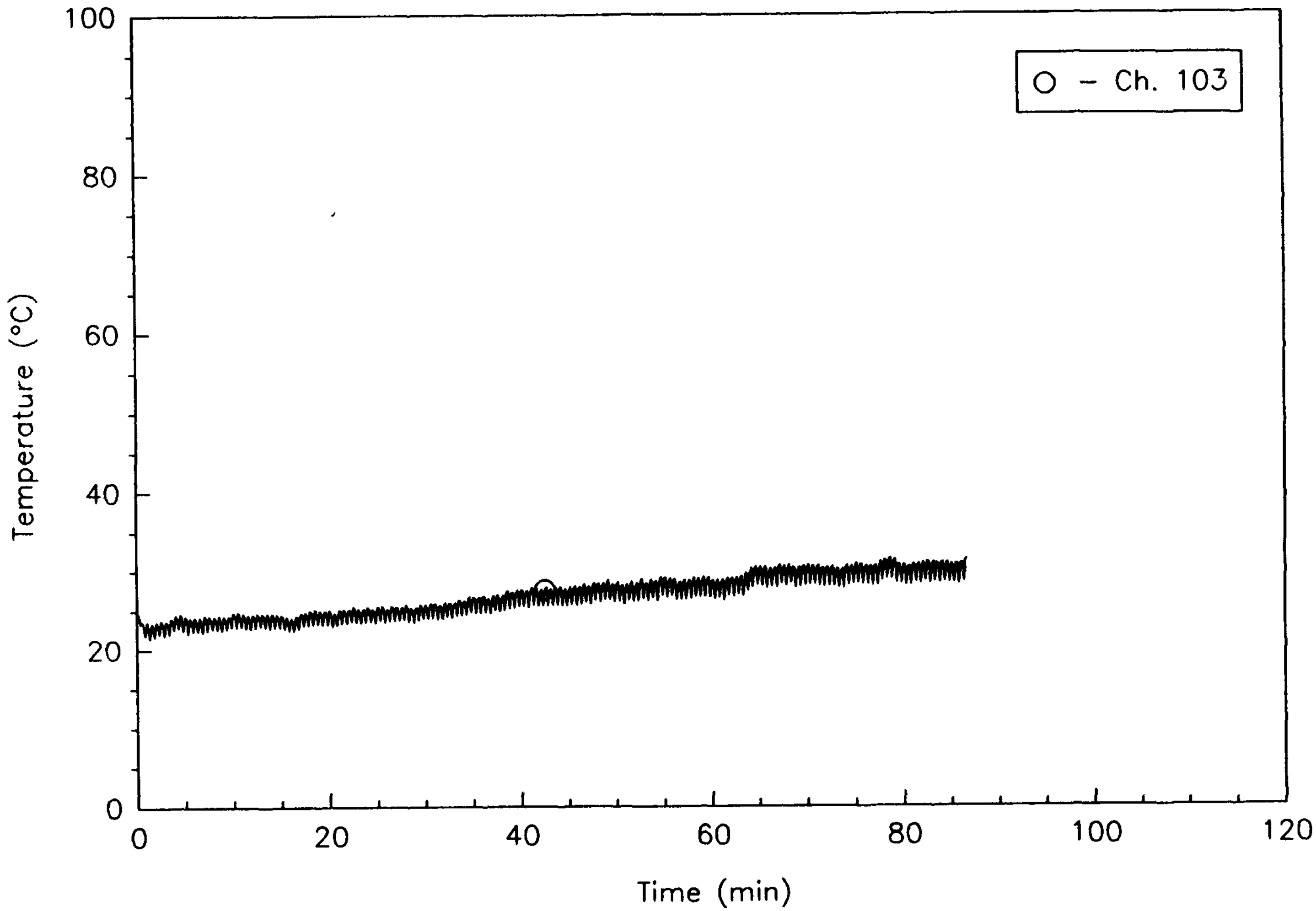

Fig. B105 – Air temperature at 2–11–2 in the port passageway
276.9 cm. (109 in.) above the deck

FD_F11

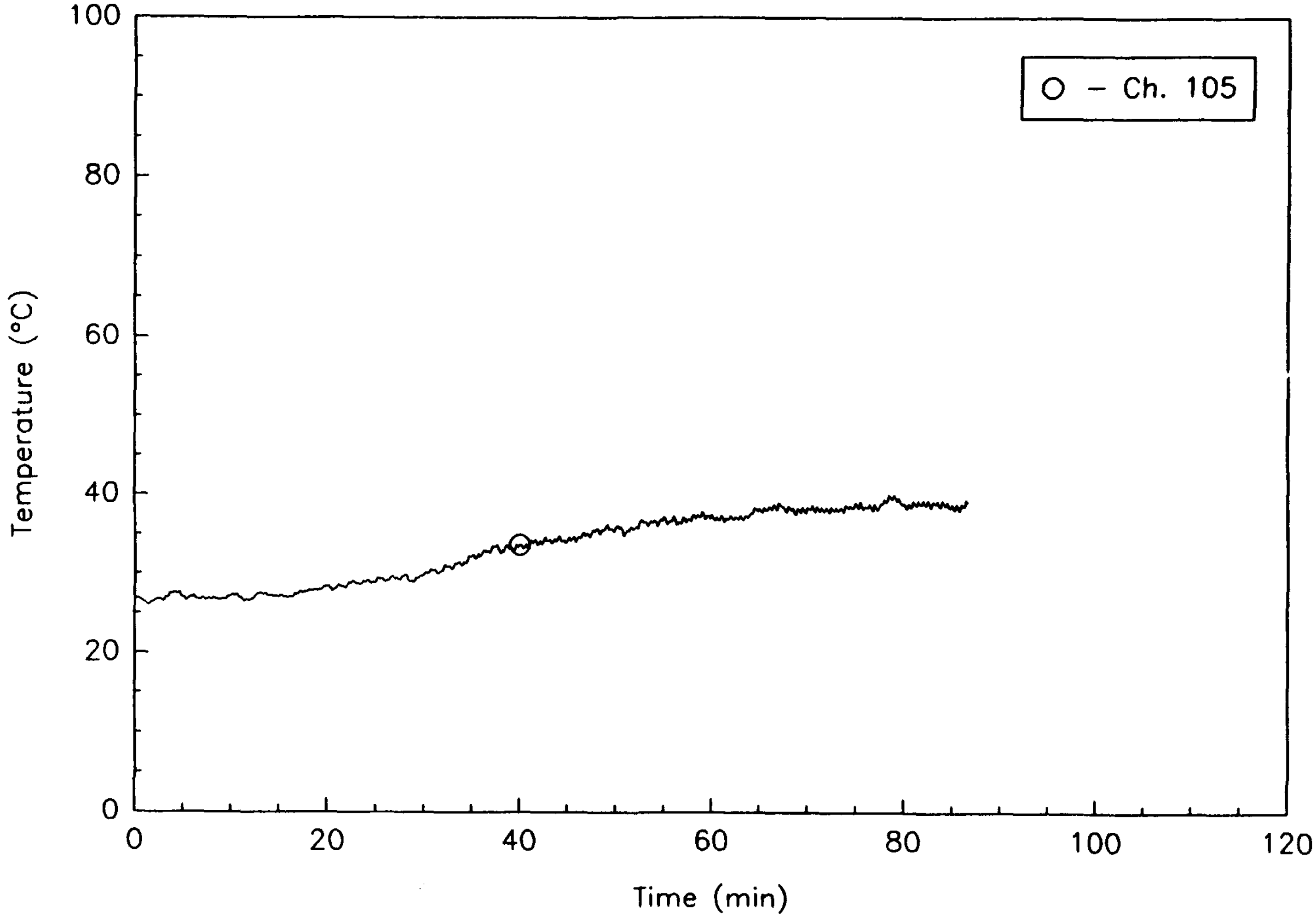

Fig. B106 – Bulkhead temperature at 2–22–2 in the port passageway 152.4 cm. (60 in.) above the deck

FD_F11

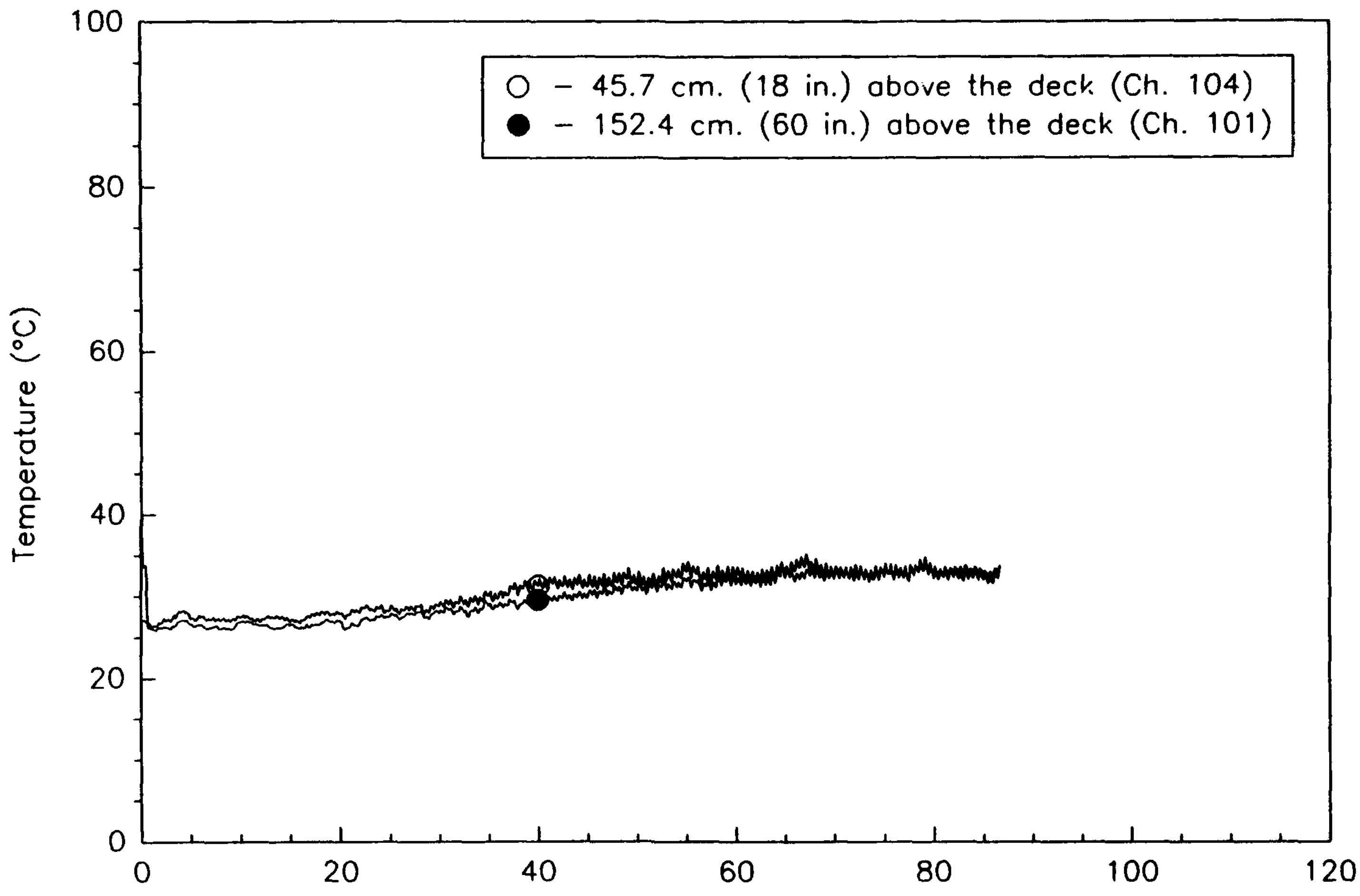

Fig. B107 – Bulkhead temperature at 2–23–2 in the port passageway

FD_F11

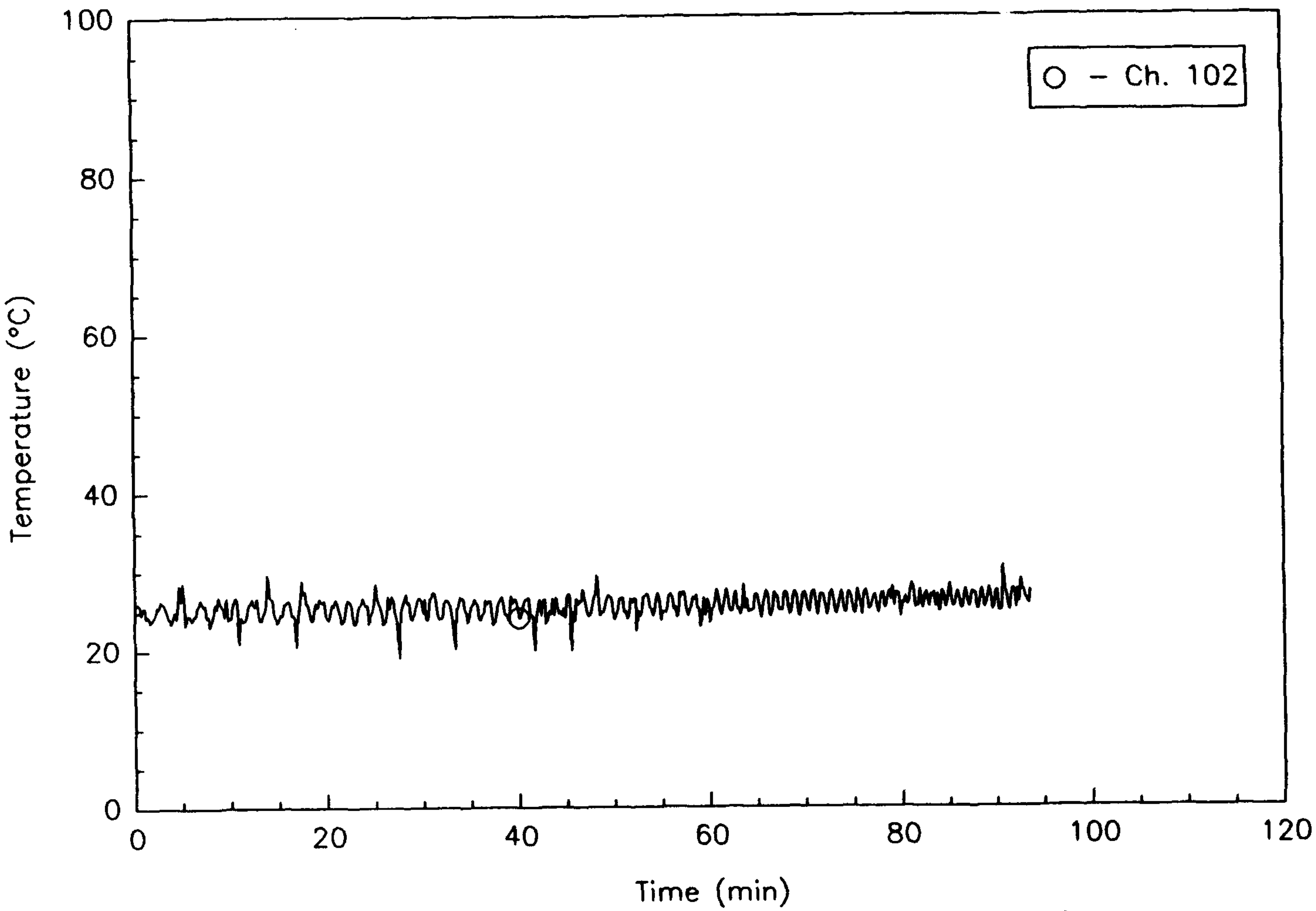

Fig. B108 – Bulkhead temperature at 2–26–2 152.4 cm. (60 in.) above the deck

FD_F11

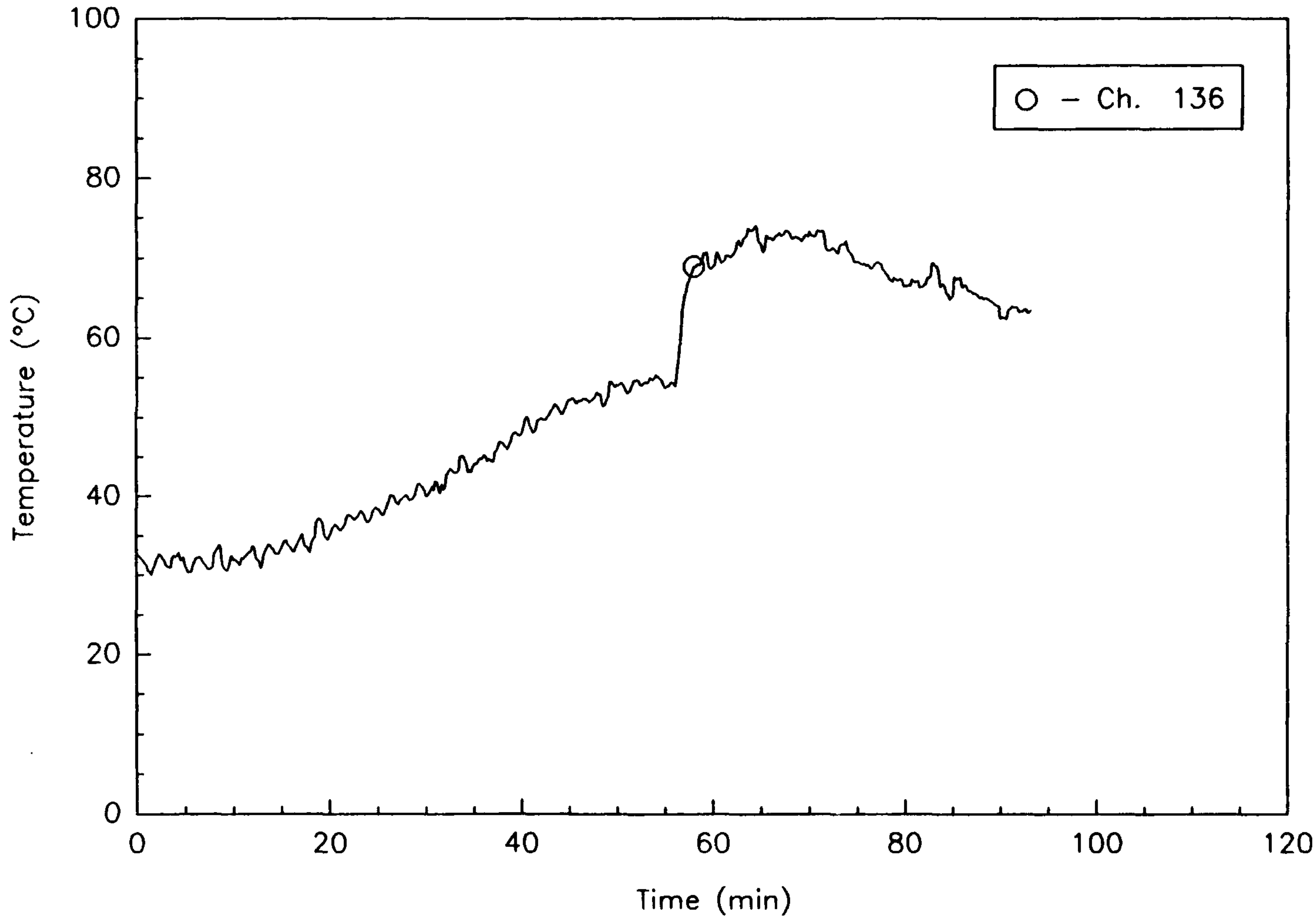

Fig. B109 – Air temperature at 1–17–0 30.5 cm. (12 in.) below overhead

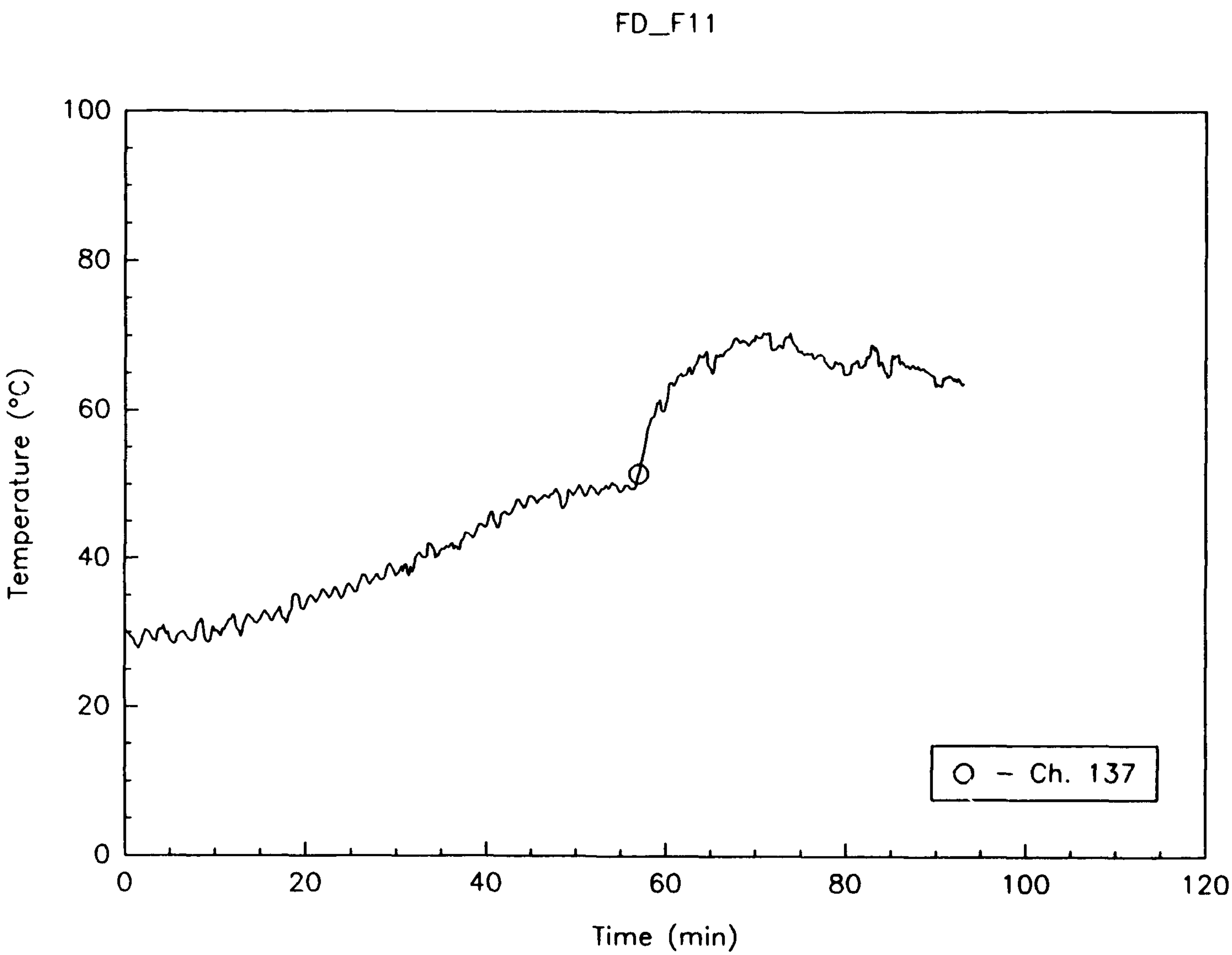

Fig. B110 – Air temperature at 1–21–0 152.4 cm. (60 in.) above the deck

FD_F11

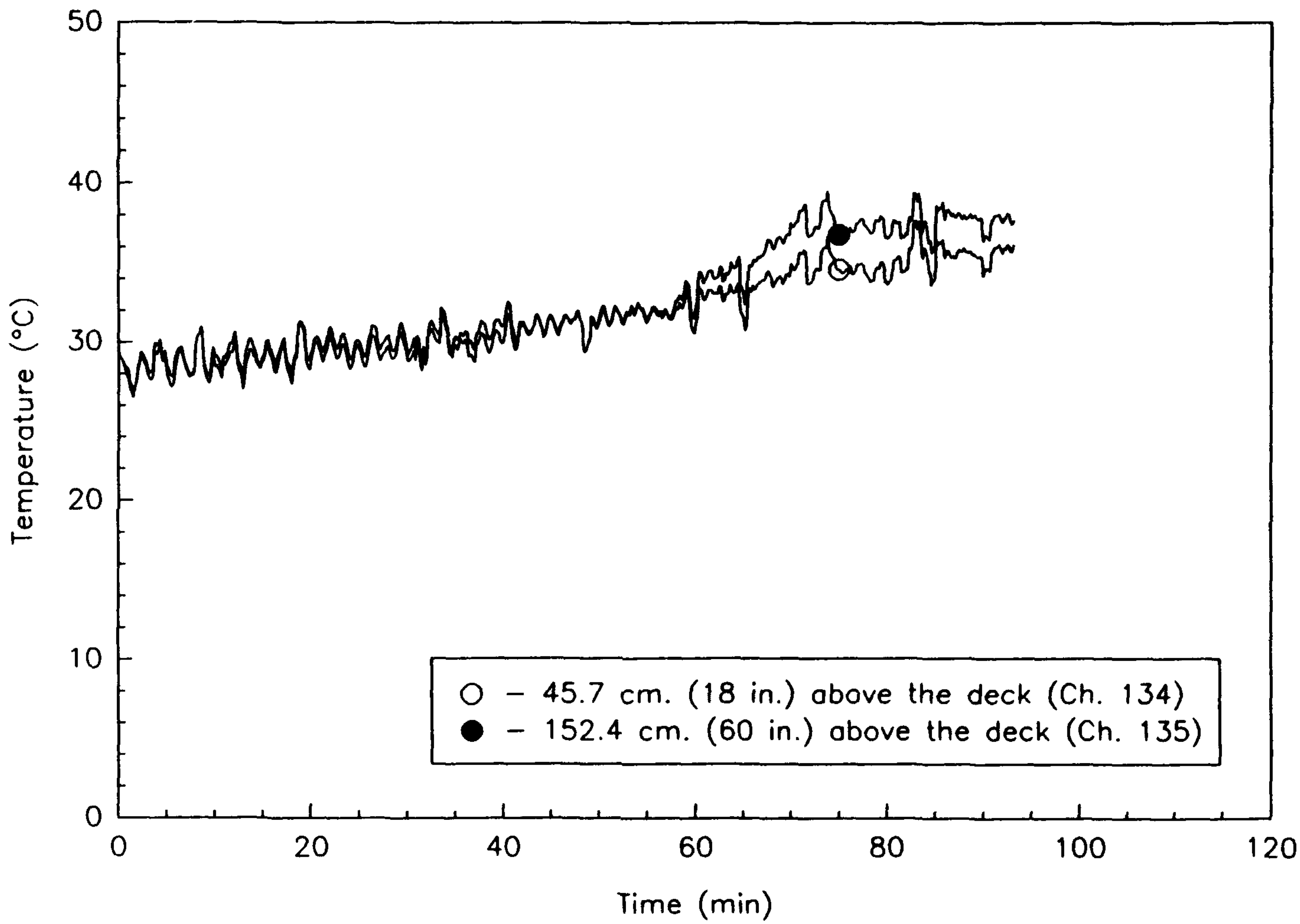

Fig. B111 – Air temperature at 1–26–0

FD_F11

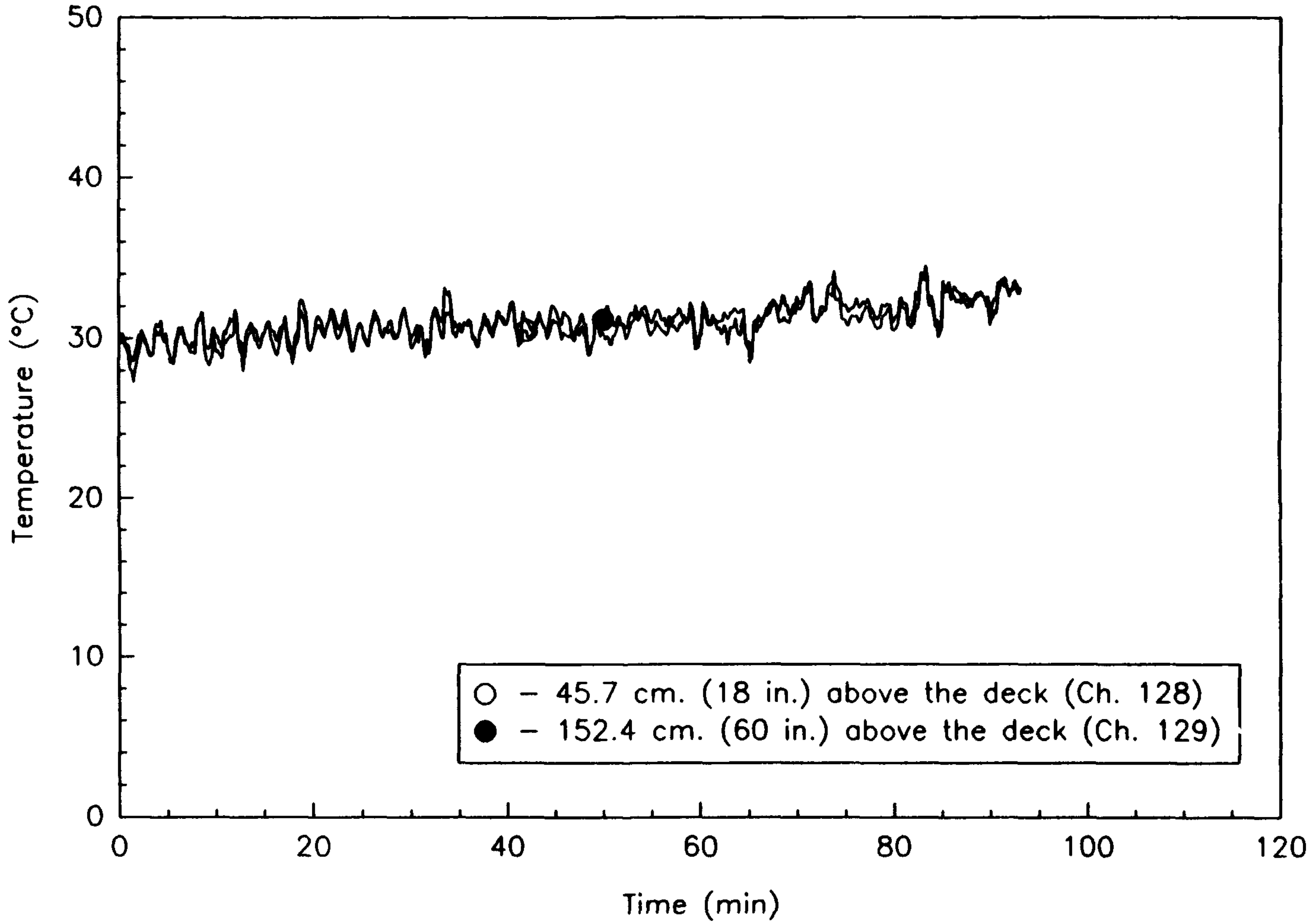

Fig. B112 – Air temperature at 1–23–1 in starboard passageway

FD_F11

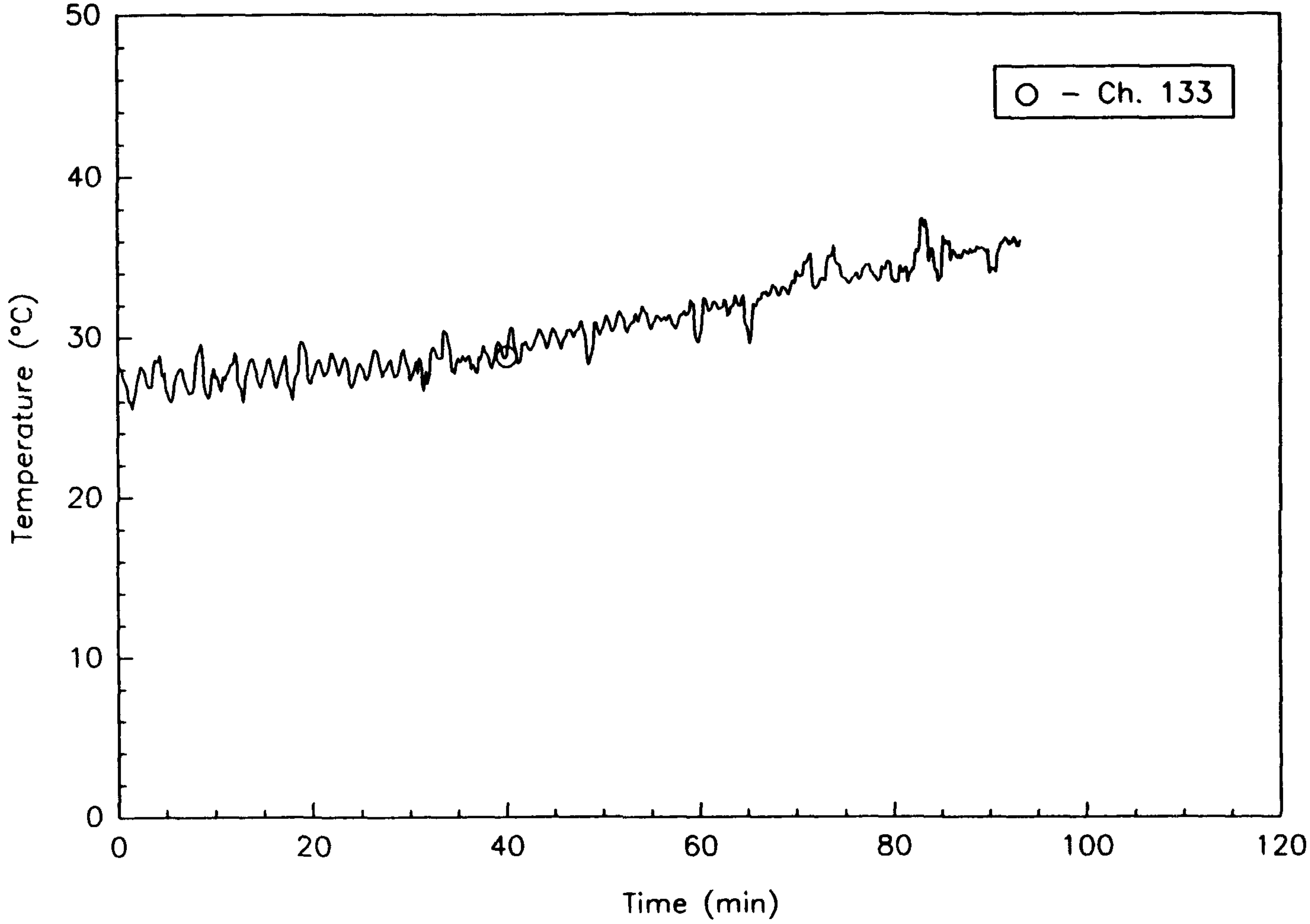

Fig. B113 – Deck temperature at 1–26–0

FD_F11

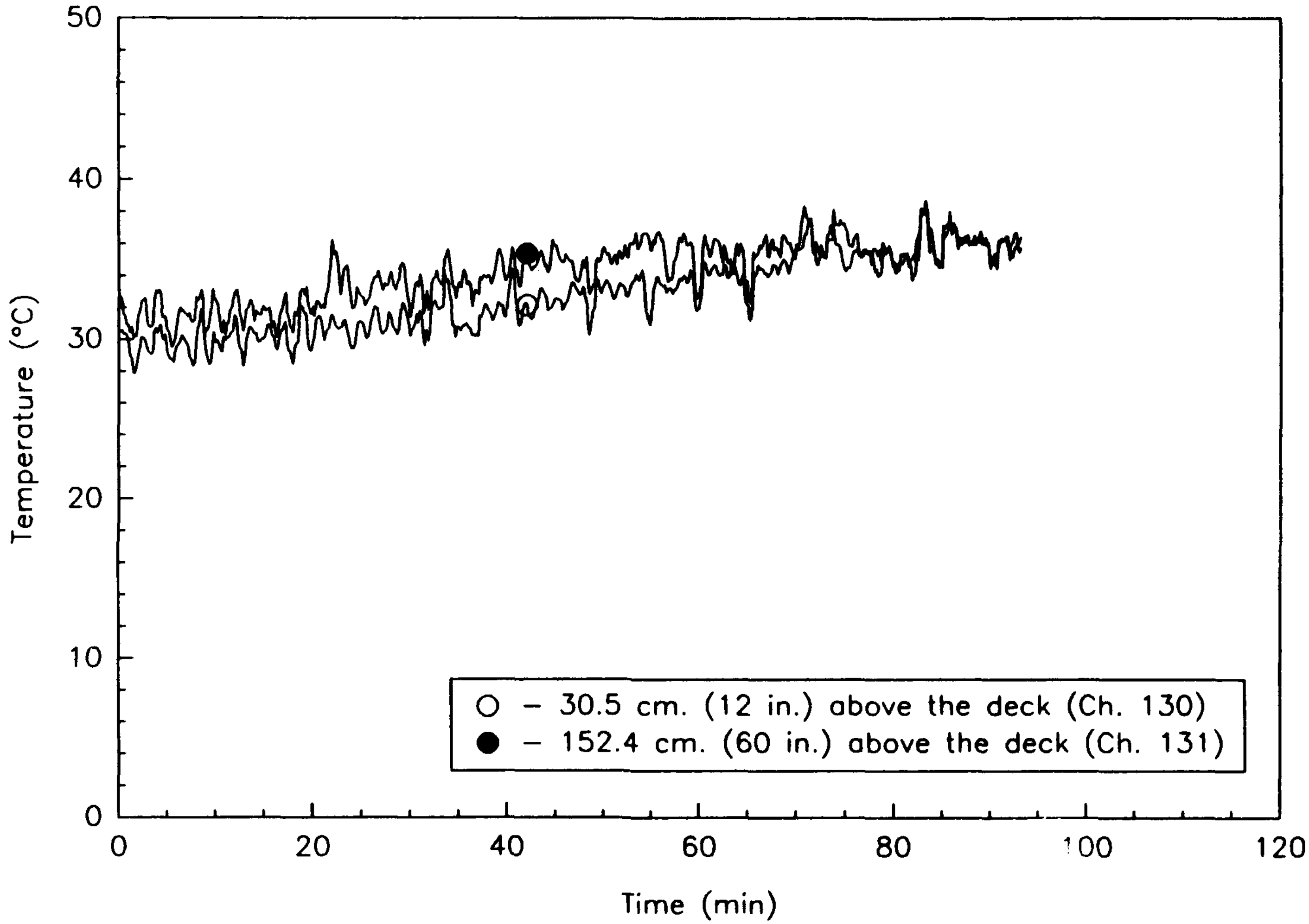

Fig. B114 – Bulkhead temperature at 1–24–1 in the Emergency Diesel Generator Room

FD_F11

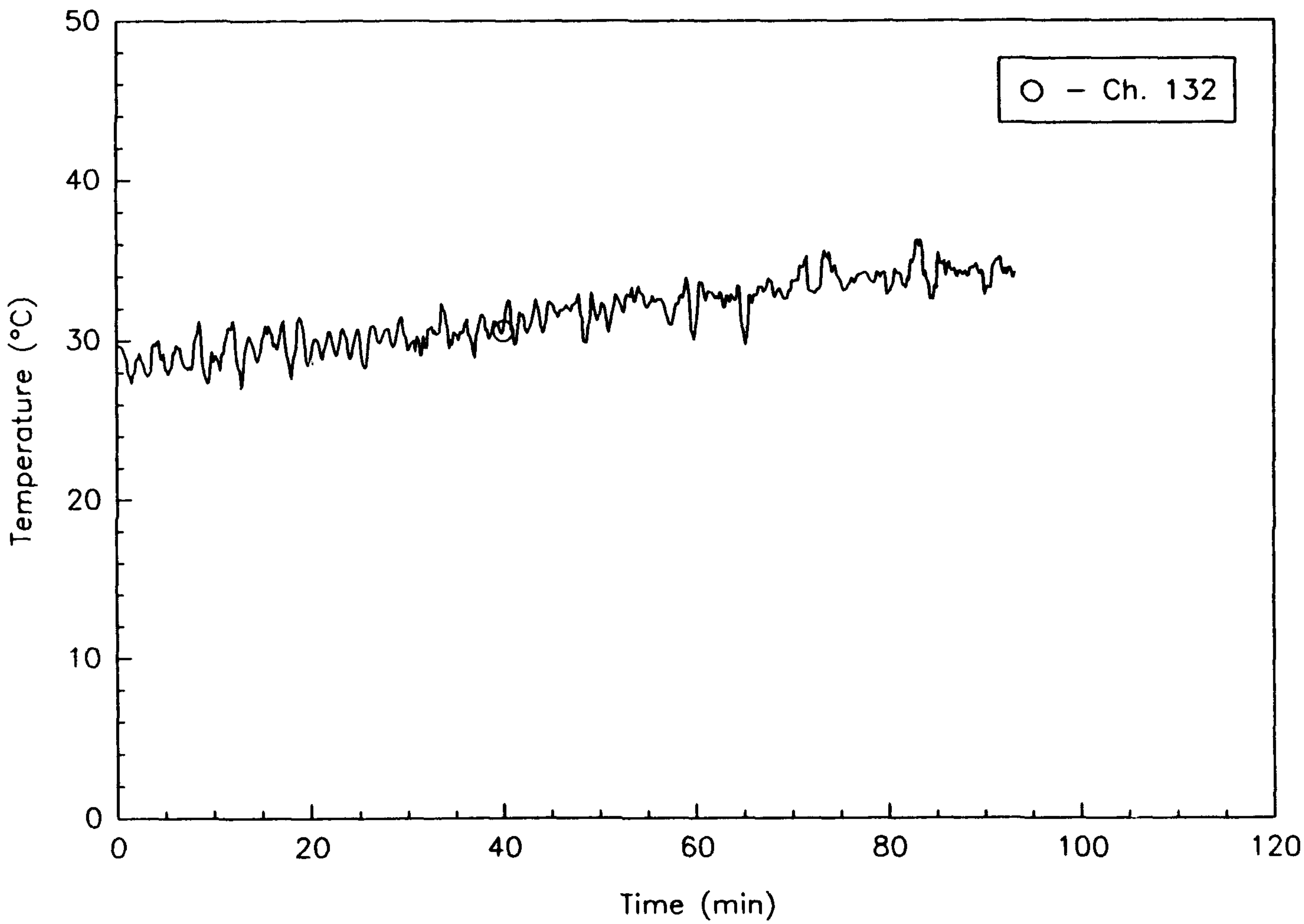

Fig. B115 – Deck temperature at 1–25–1 in the Emergency Diesel Generator Room

FD_F11

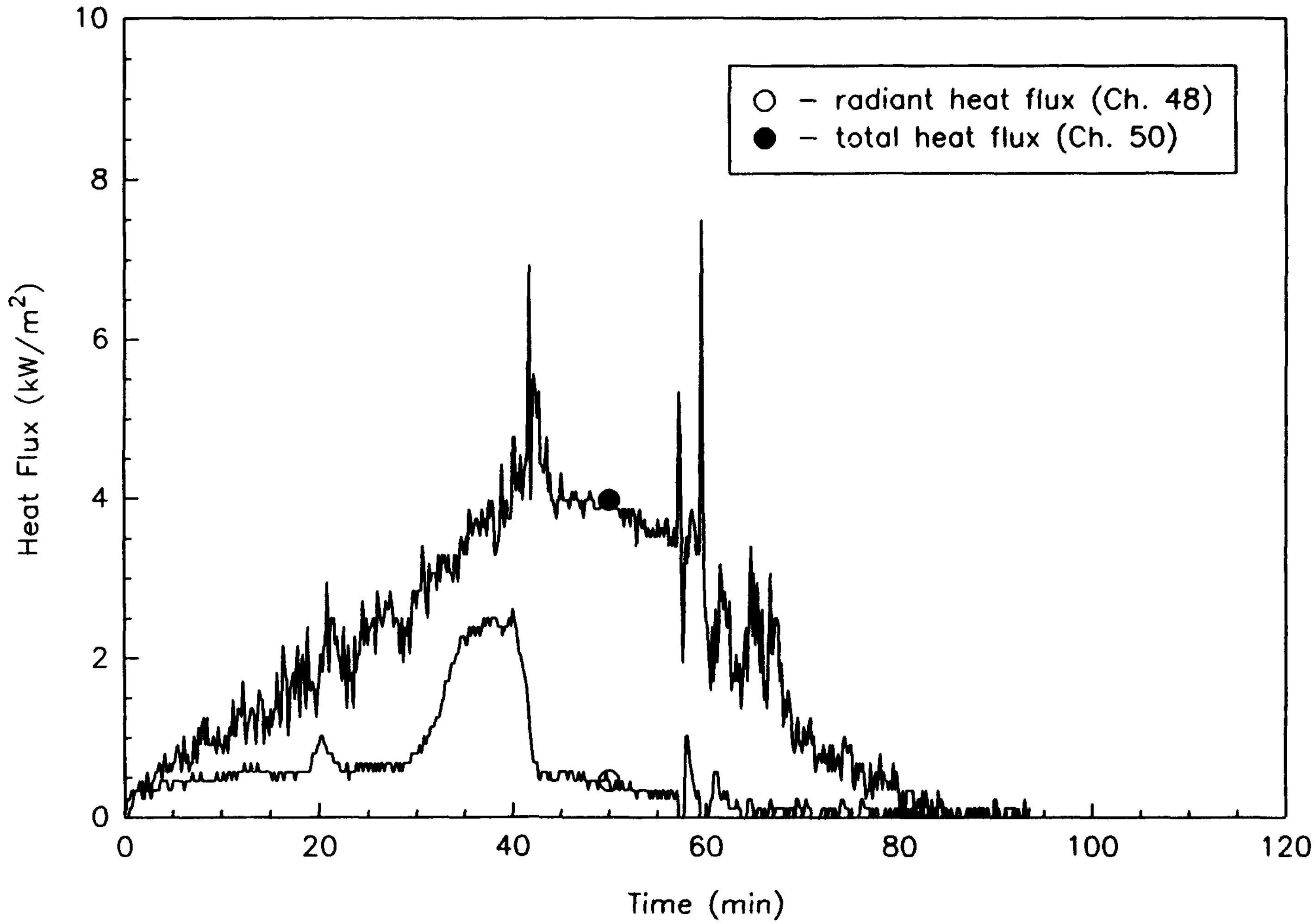

Fig. B116 – Heat flux at 3–20–1 viewing crib # 1

FD_F11

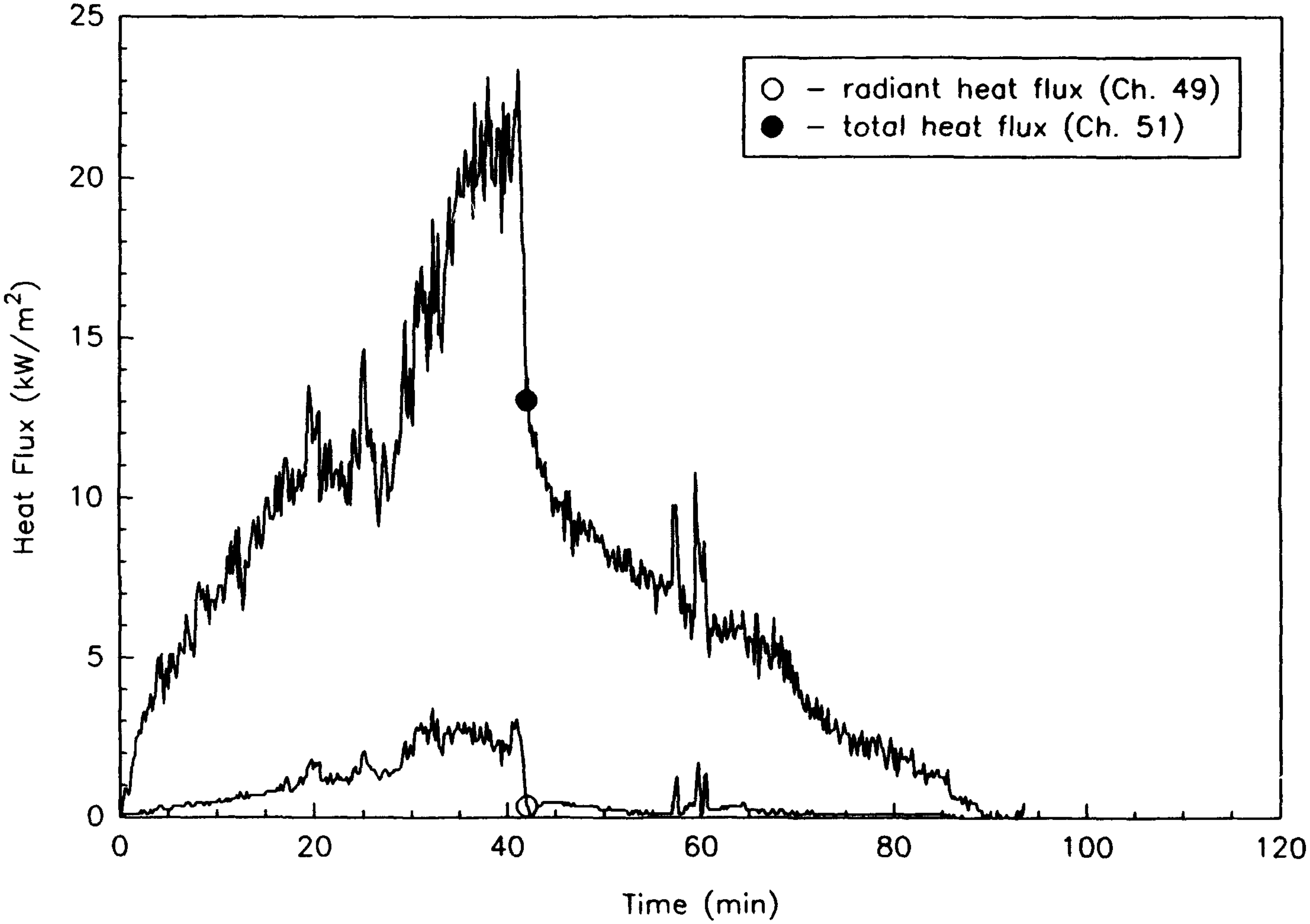

Fig. B117 – Heat flux at 3–20–0 (top of hatch)

FD_F11

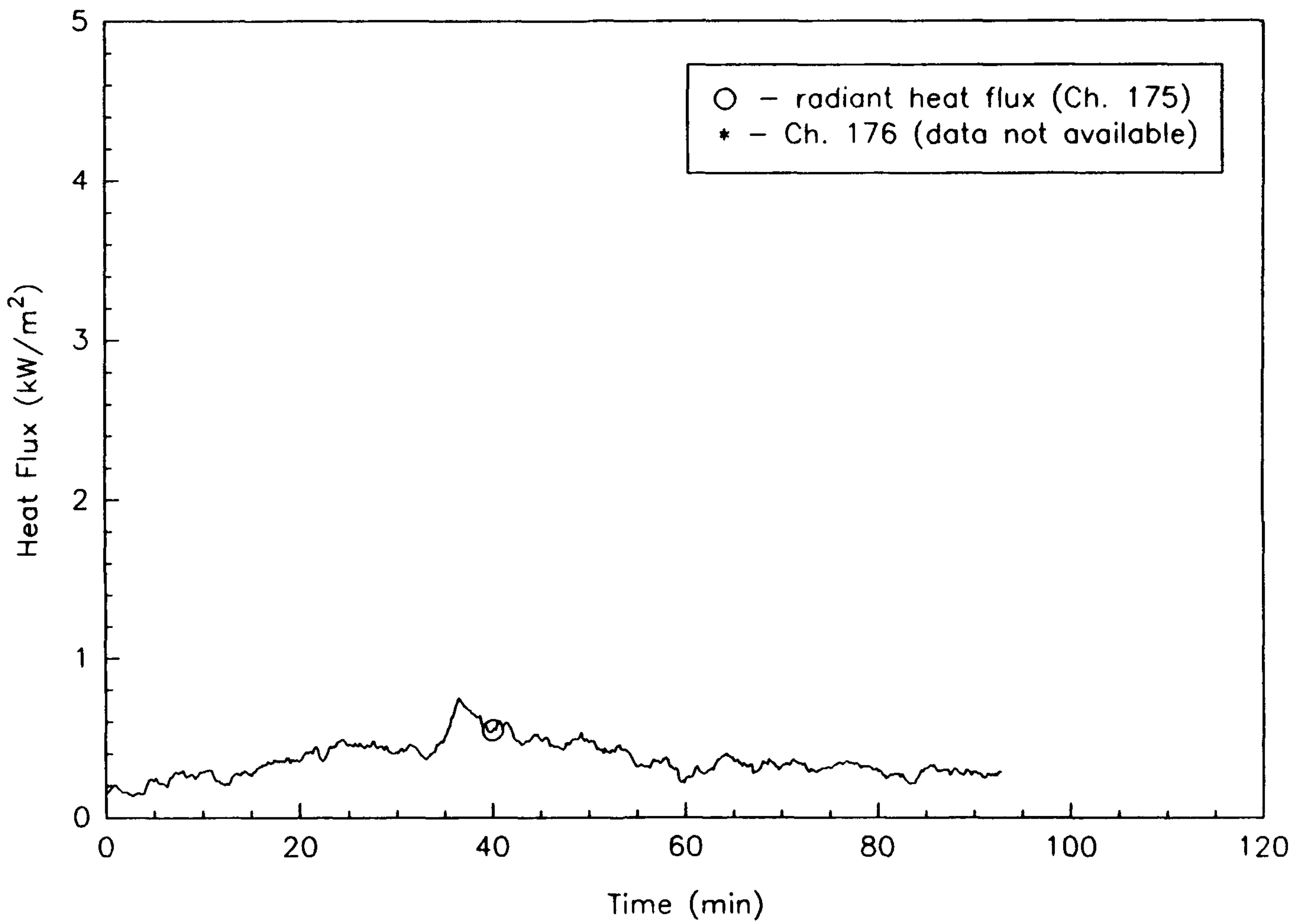

Fig. B118 – Heat flux at 2–21–0 viewing hatch

FD_F11

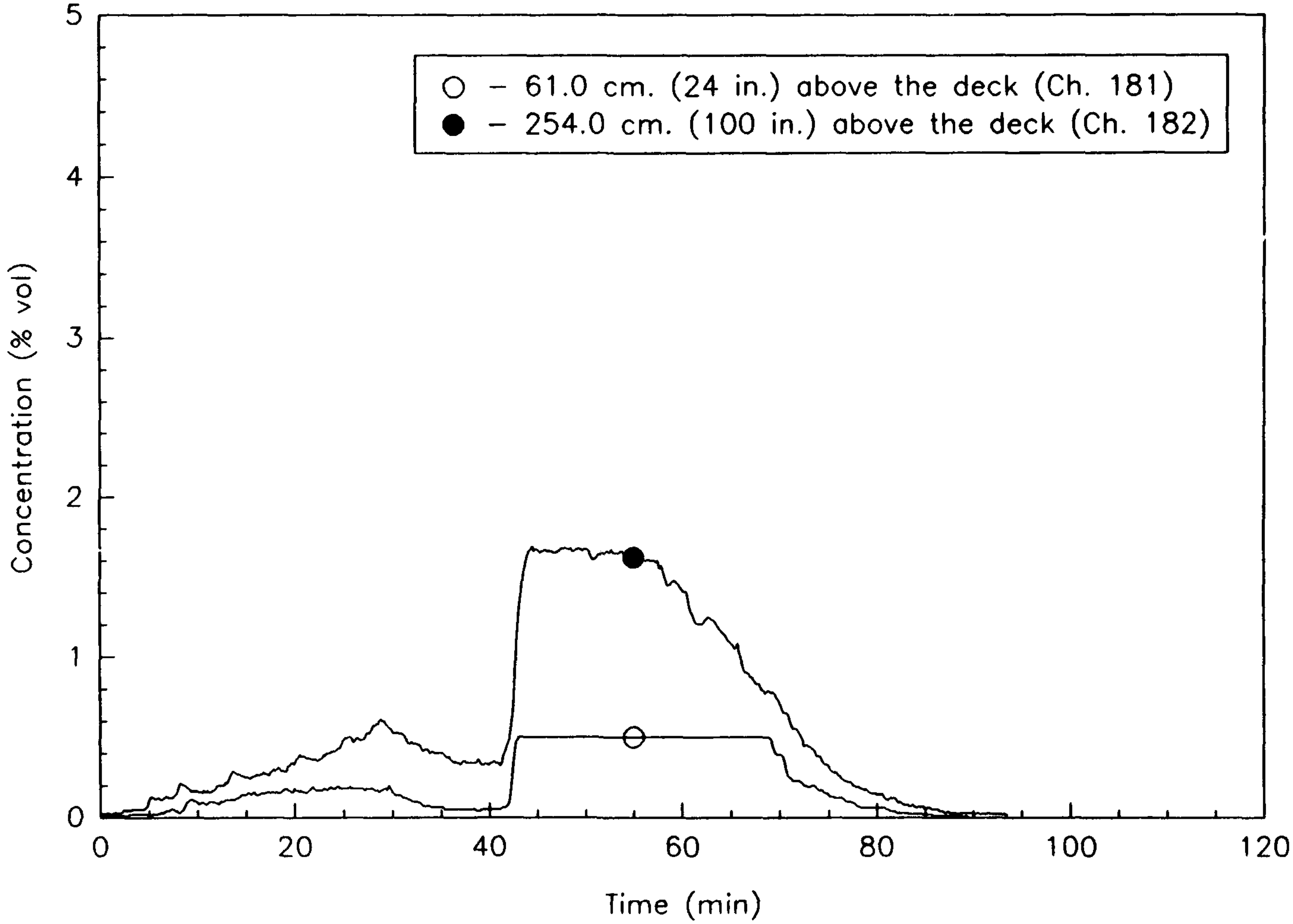

Fig. B119 – Carbon monoxide concentrations at 3–20–2

FD_F11

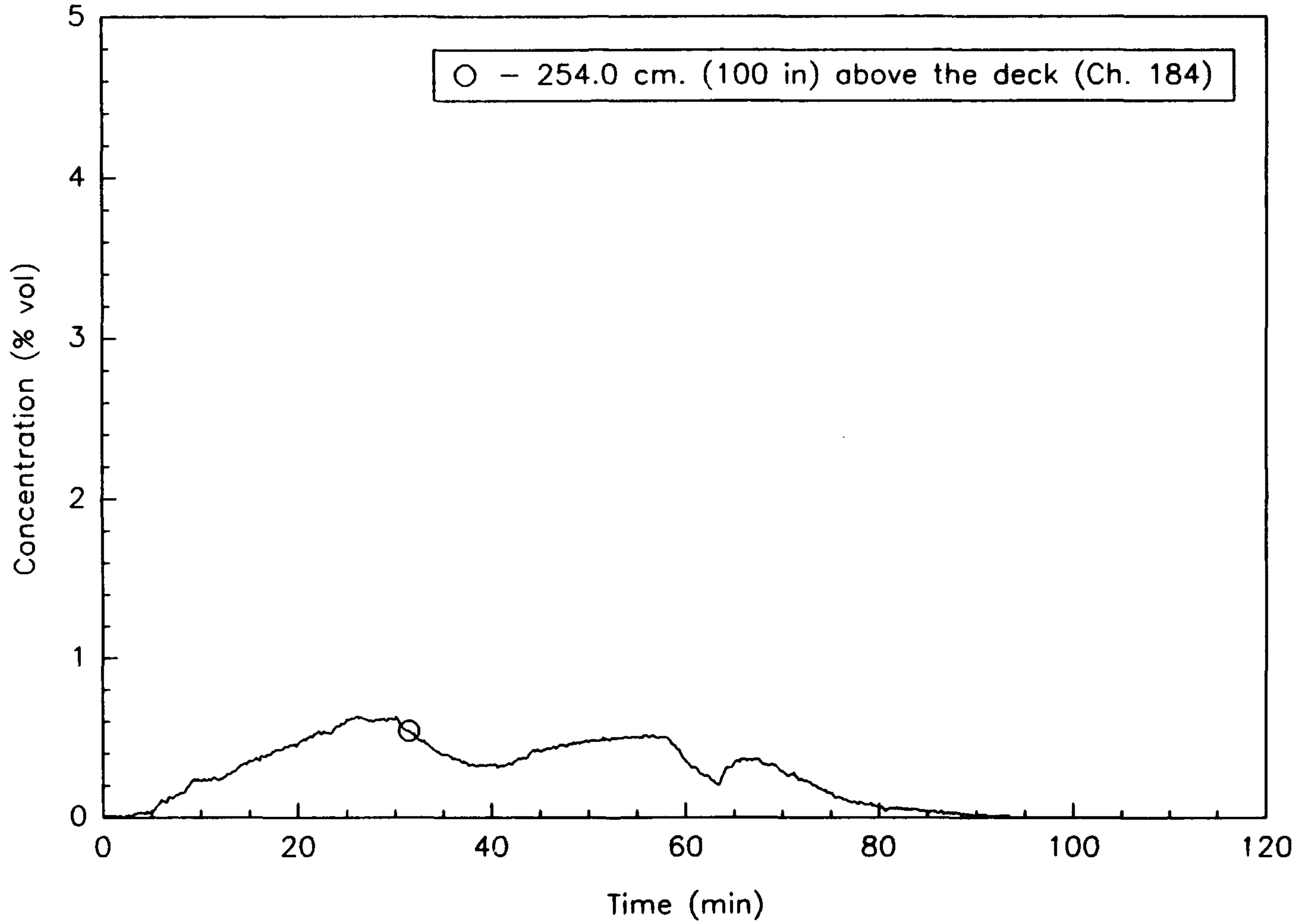

Fig. B120 – Carbon monoxide concentration at 2–17–2

FD_F11

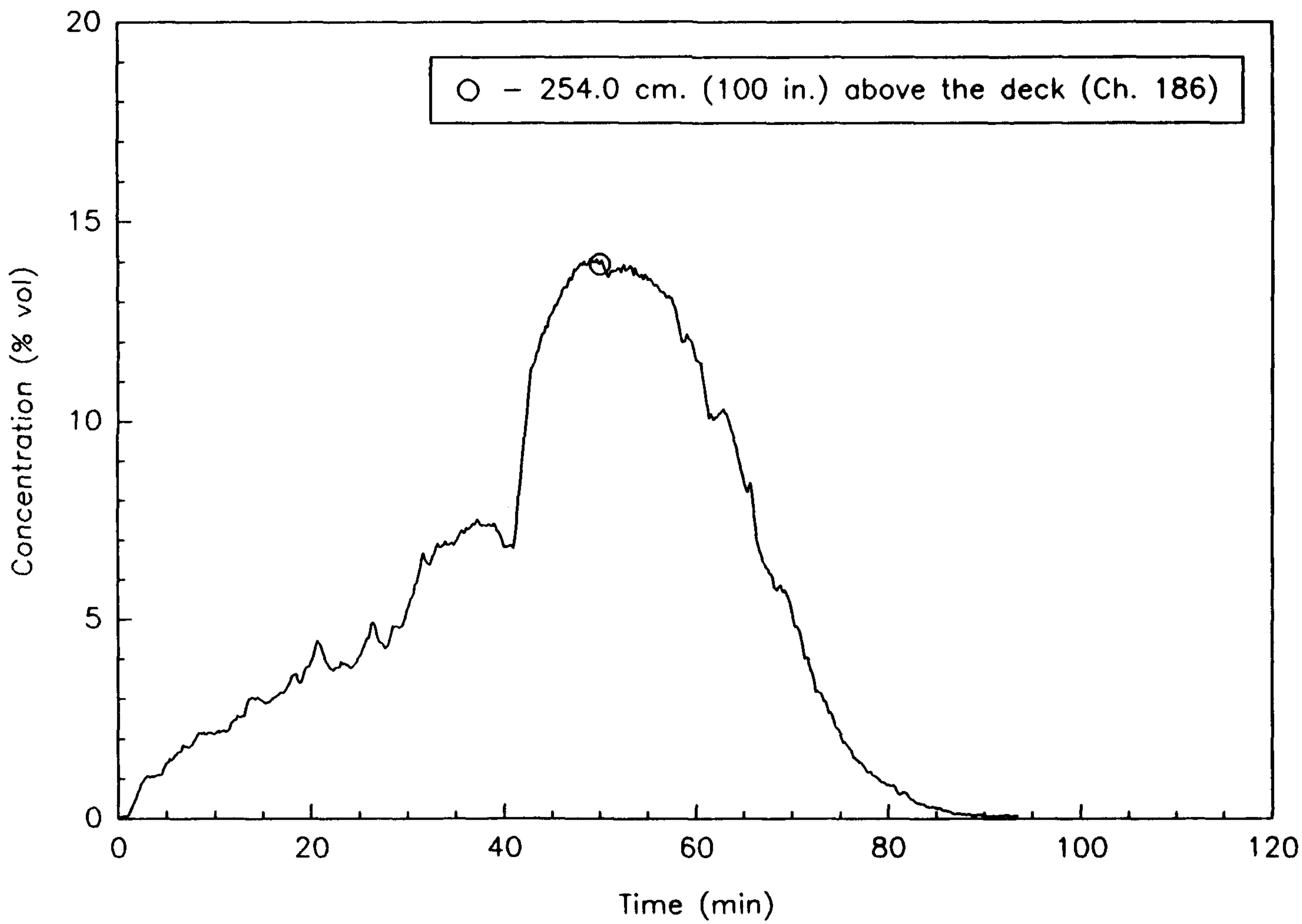

Fig. B121 – Carbon dioxide concentration at 3–20–2

FD_F11

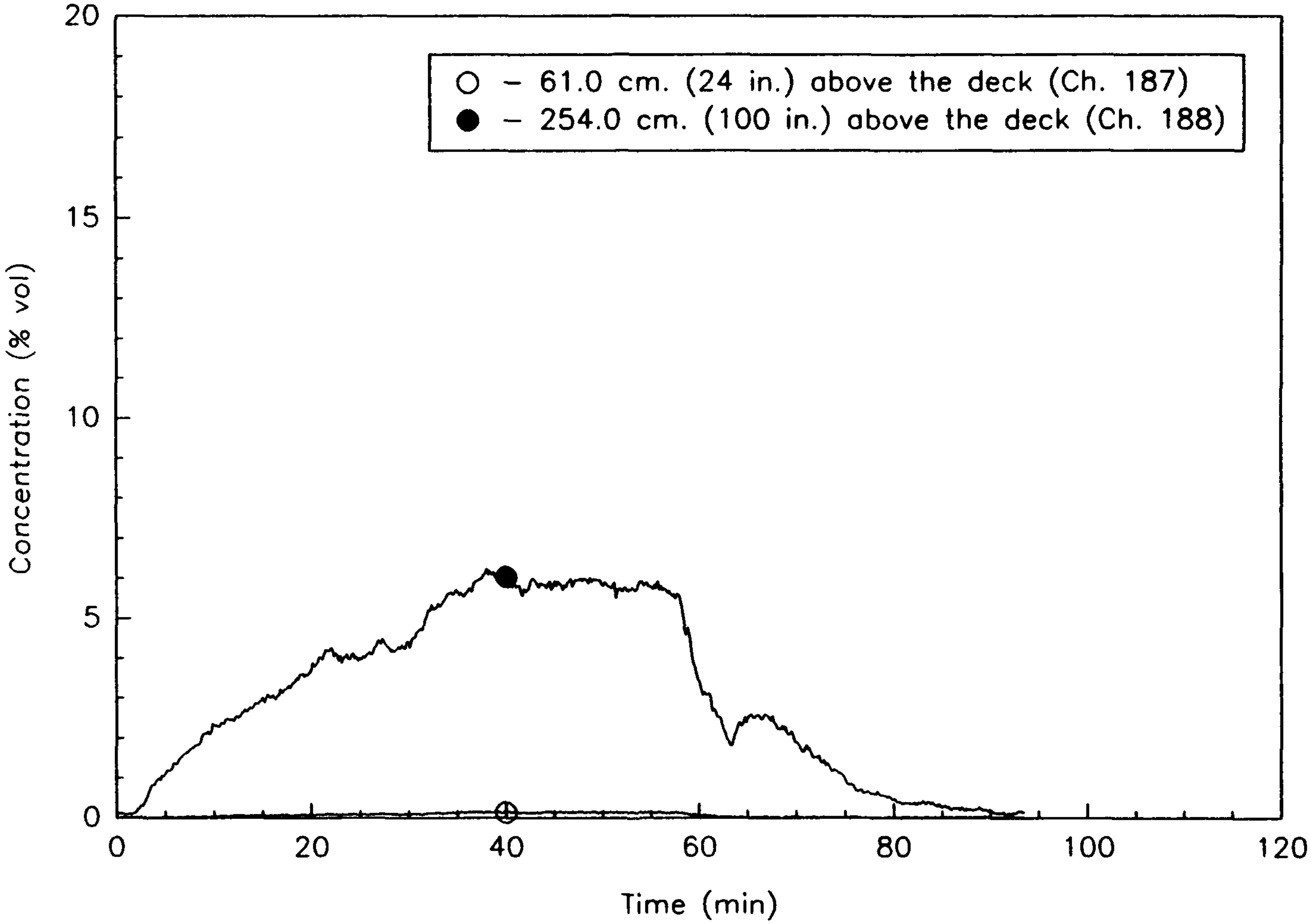

Fig. B122 – Carbon dioxide concentrations at 2–17–2

FD_F11

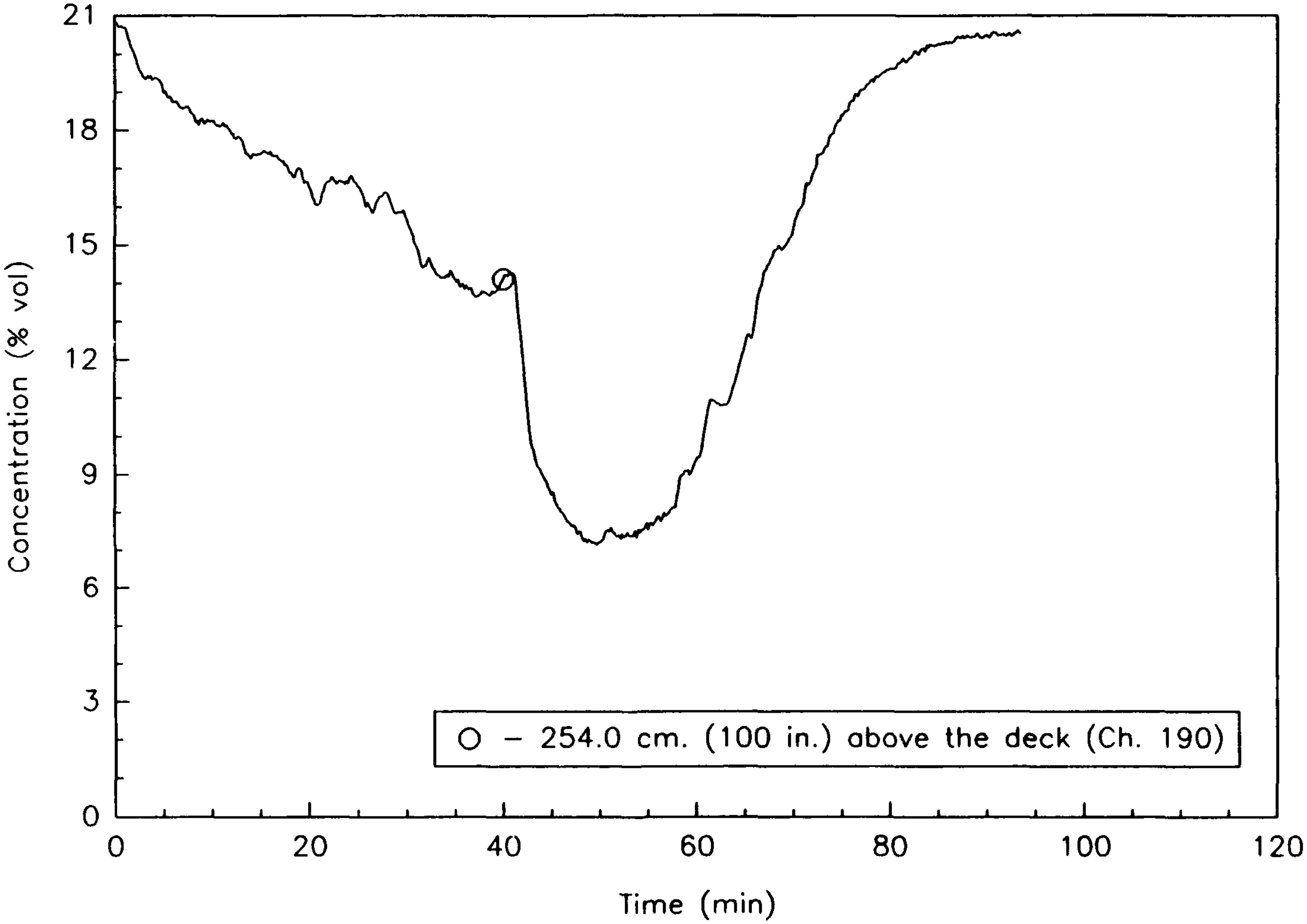

Fig. B123 – Oxygen concentration at 3–20–2

FD_F11

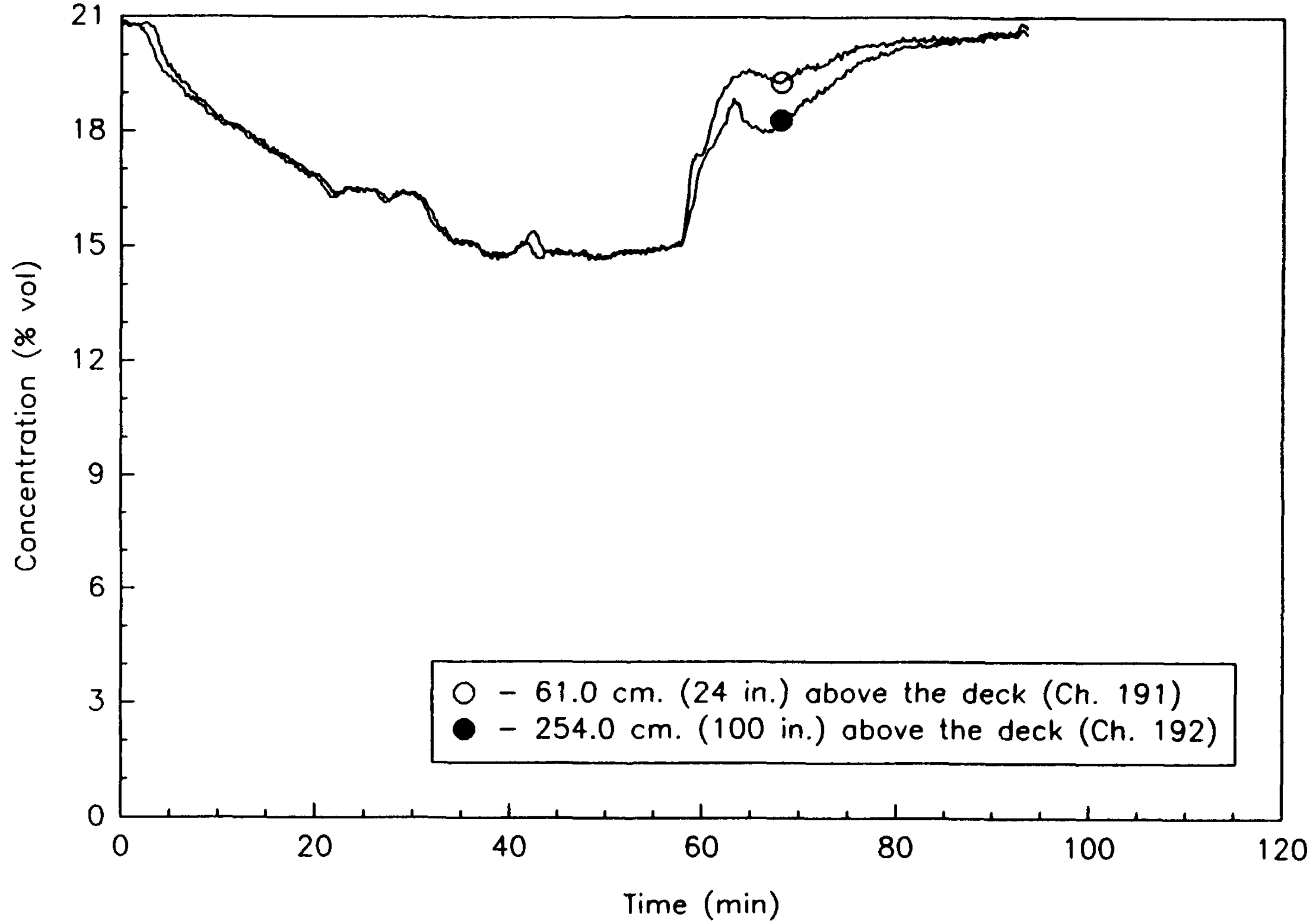

Fig. B124 – Oxygen concentrations at 2-17-2

FD_F11

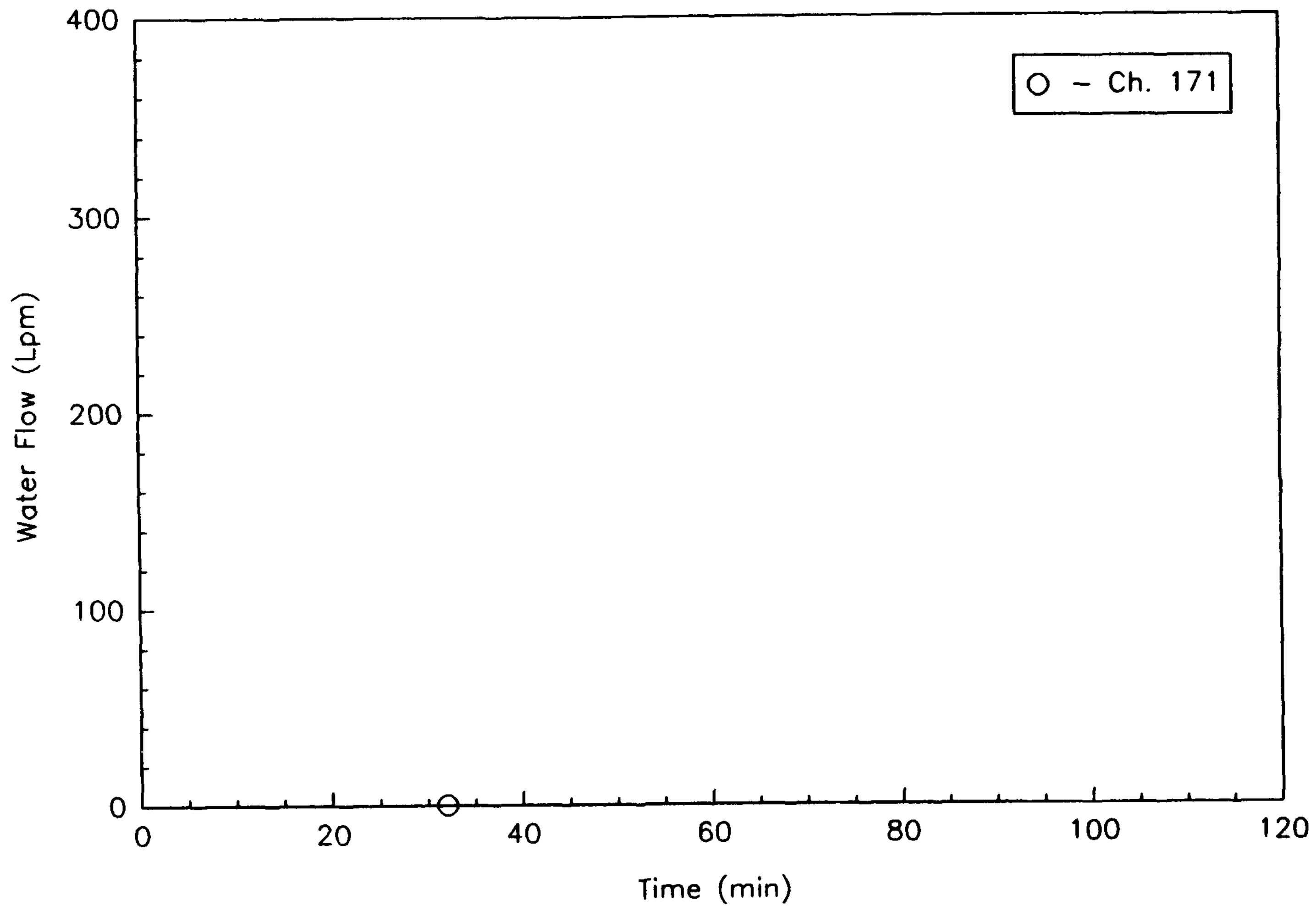

Fig. B125 – Water flow rate at 2–11–0

FD_F11

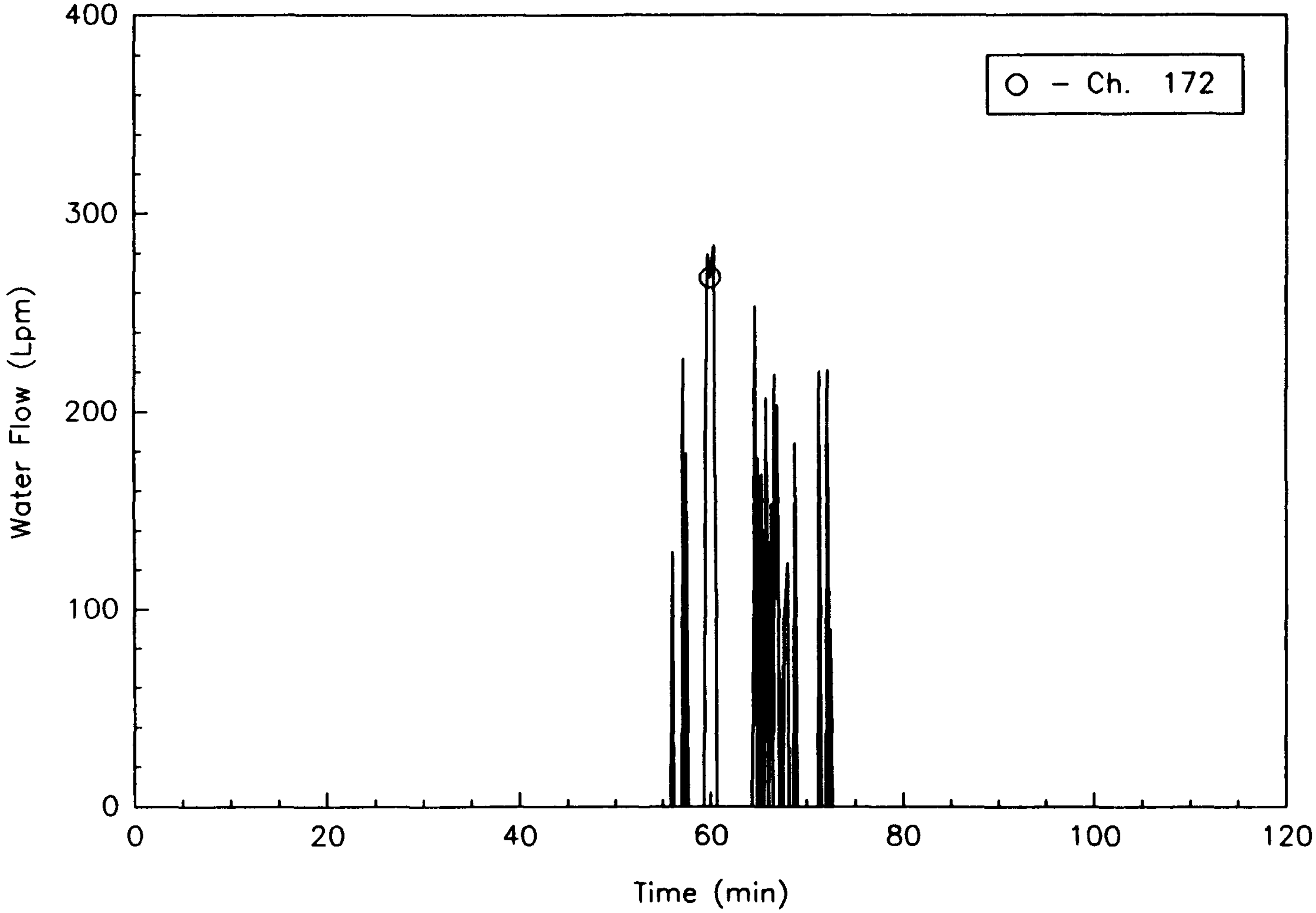

Fig. B126 – Water flow rate at 2–19–1

FD_F11

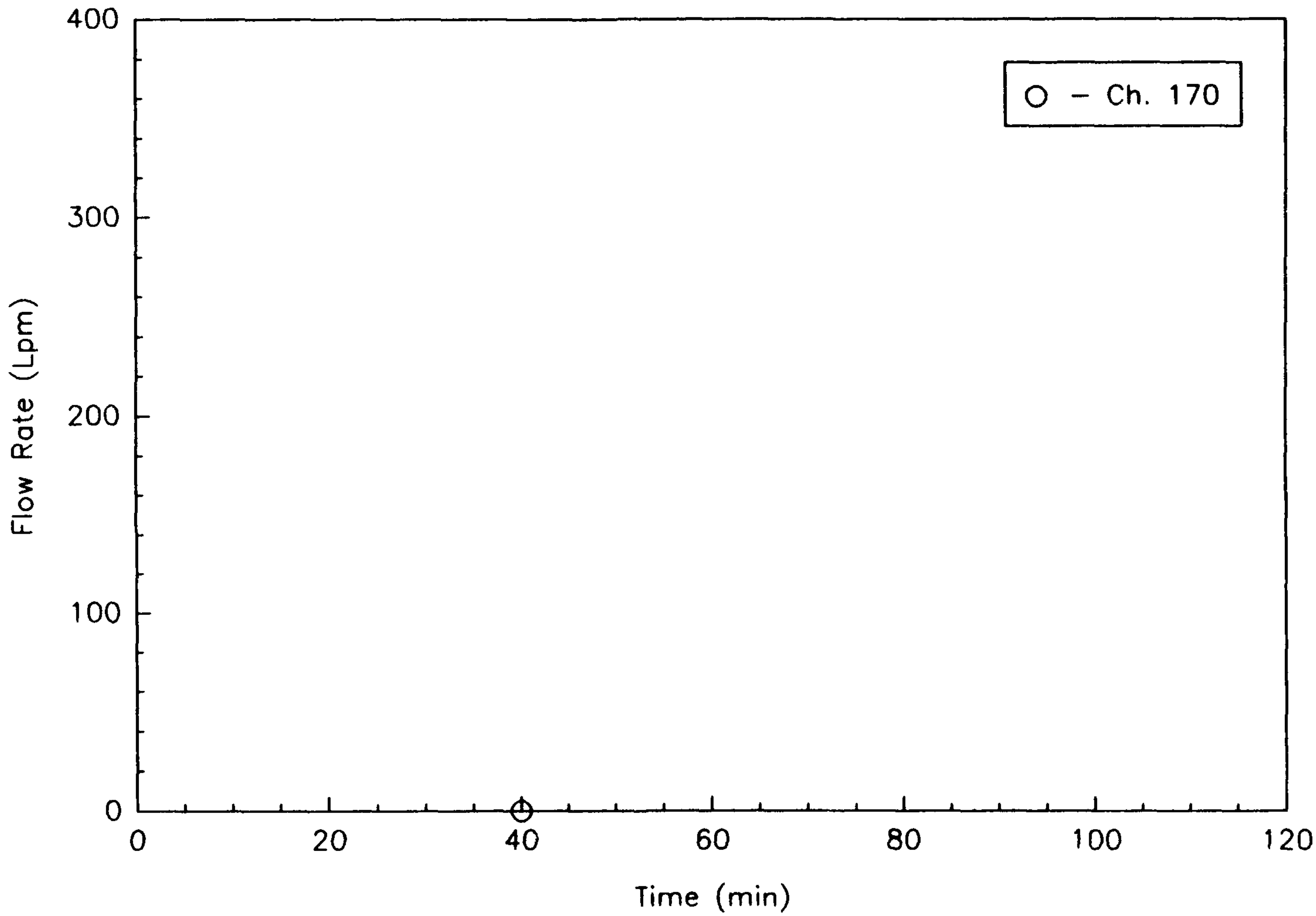

Fig. B127 – Water flow rate at 2–28–1

FD_F11

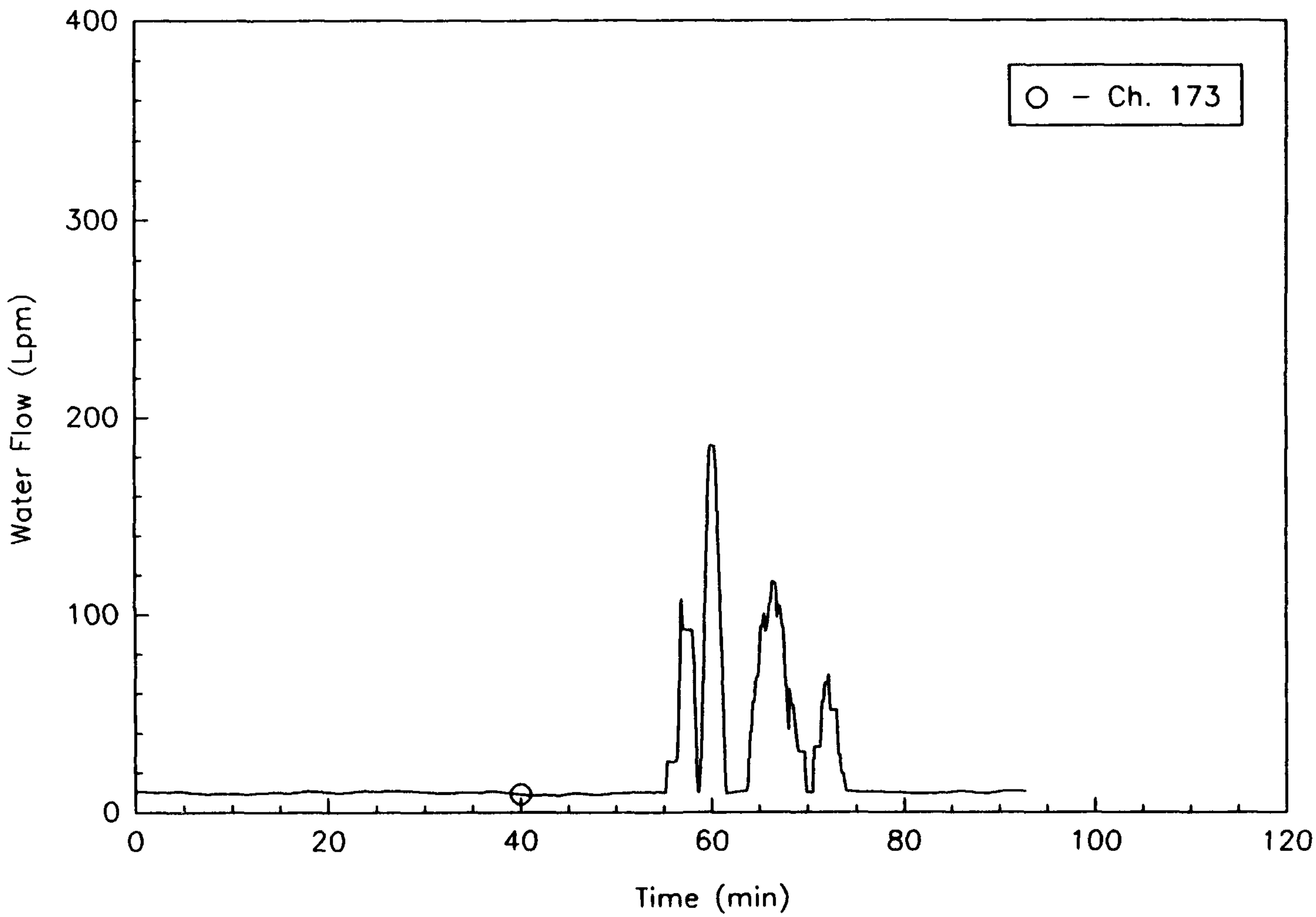

Fig. B128 – Water flow at 1–23–1

FD_F11

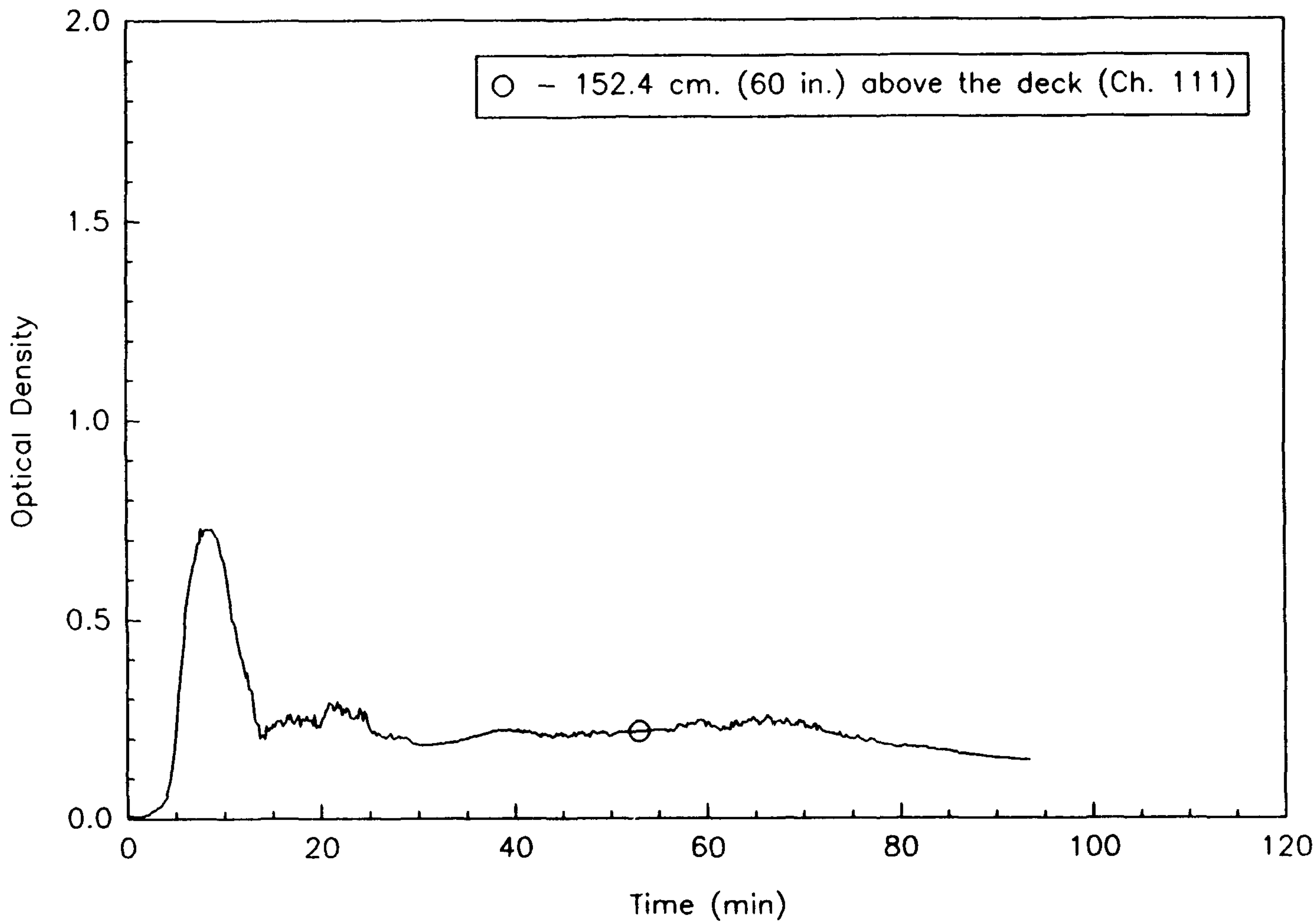

Fig. B129 – Optical density at 2–16–1 in Crew Living 1

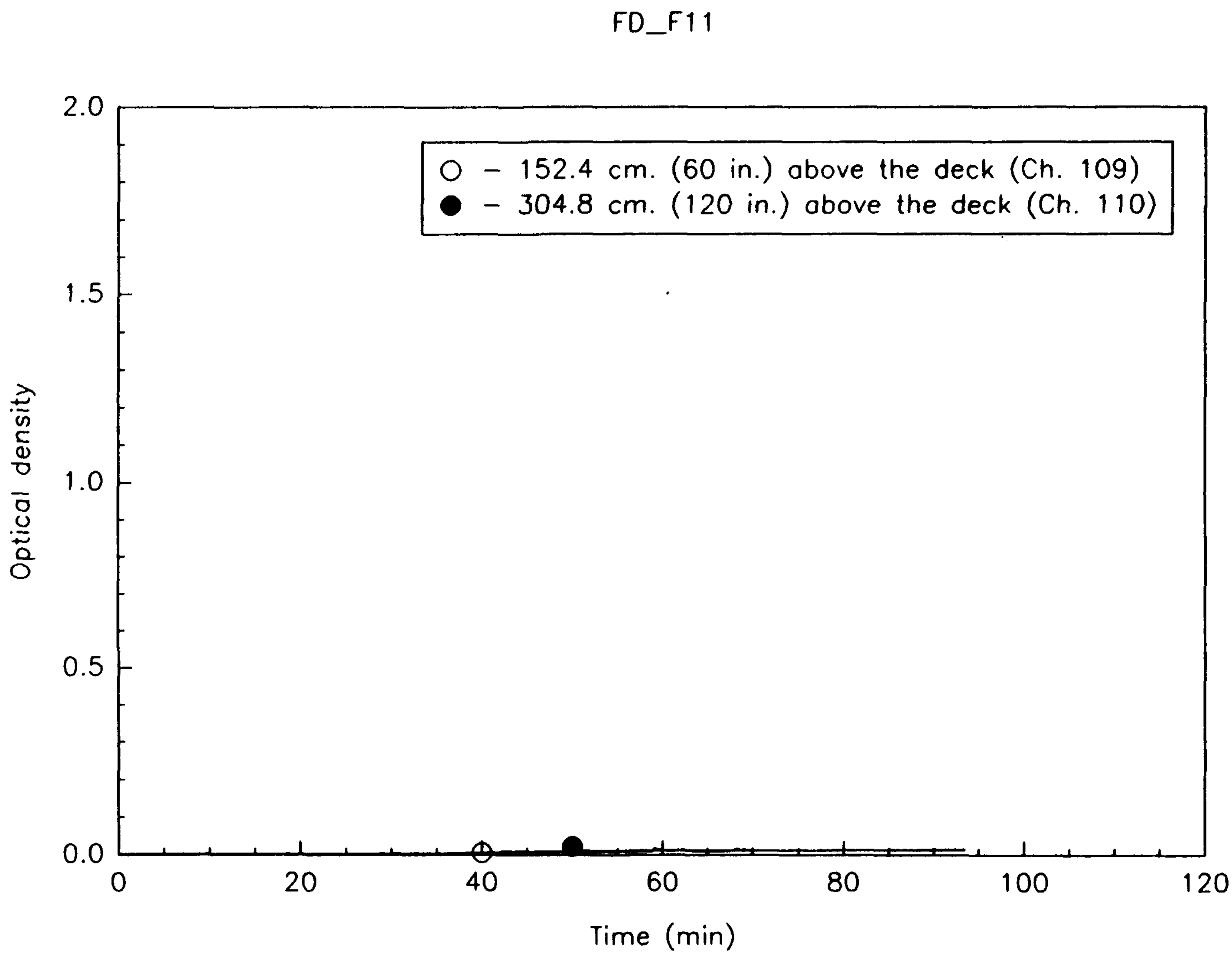

Fig. B130 – Optical density at 2–26–2 in CIC AFT

FD_F11

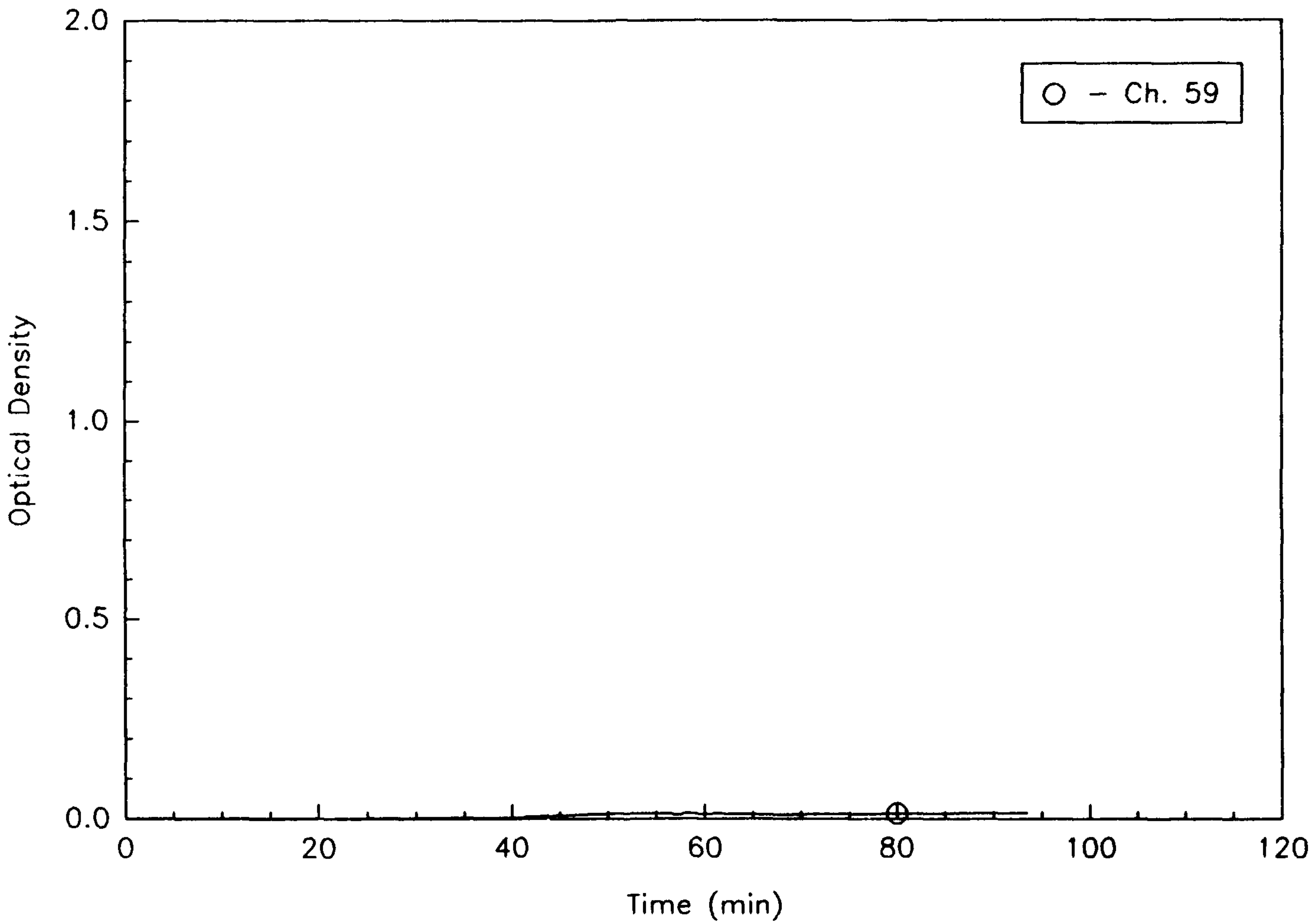

Fig. B131 – Optical density at 2–18–2 in port passageway
304.8 cm. (120 in.) above the deck

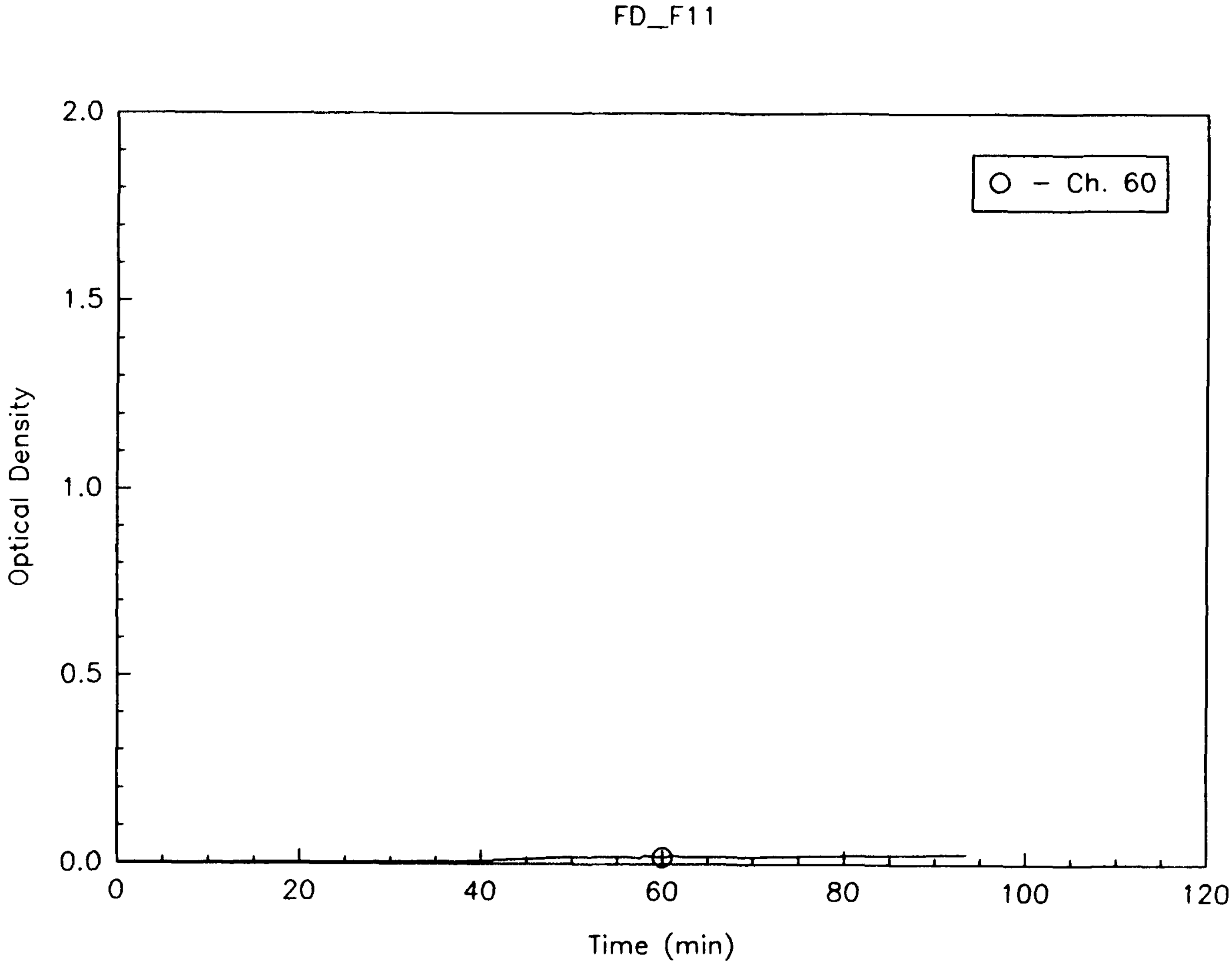

Fig. B132 - Optical density at 2-23-2 in the port passageway 152.4 cm. (60 in.) above the deck

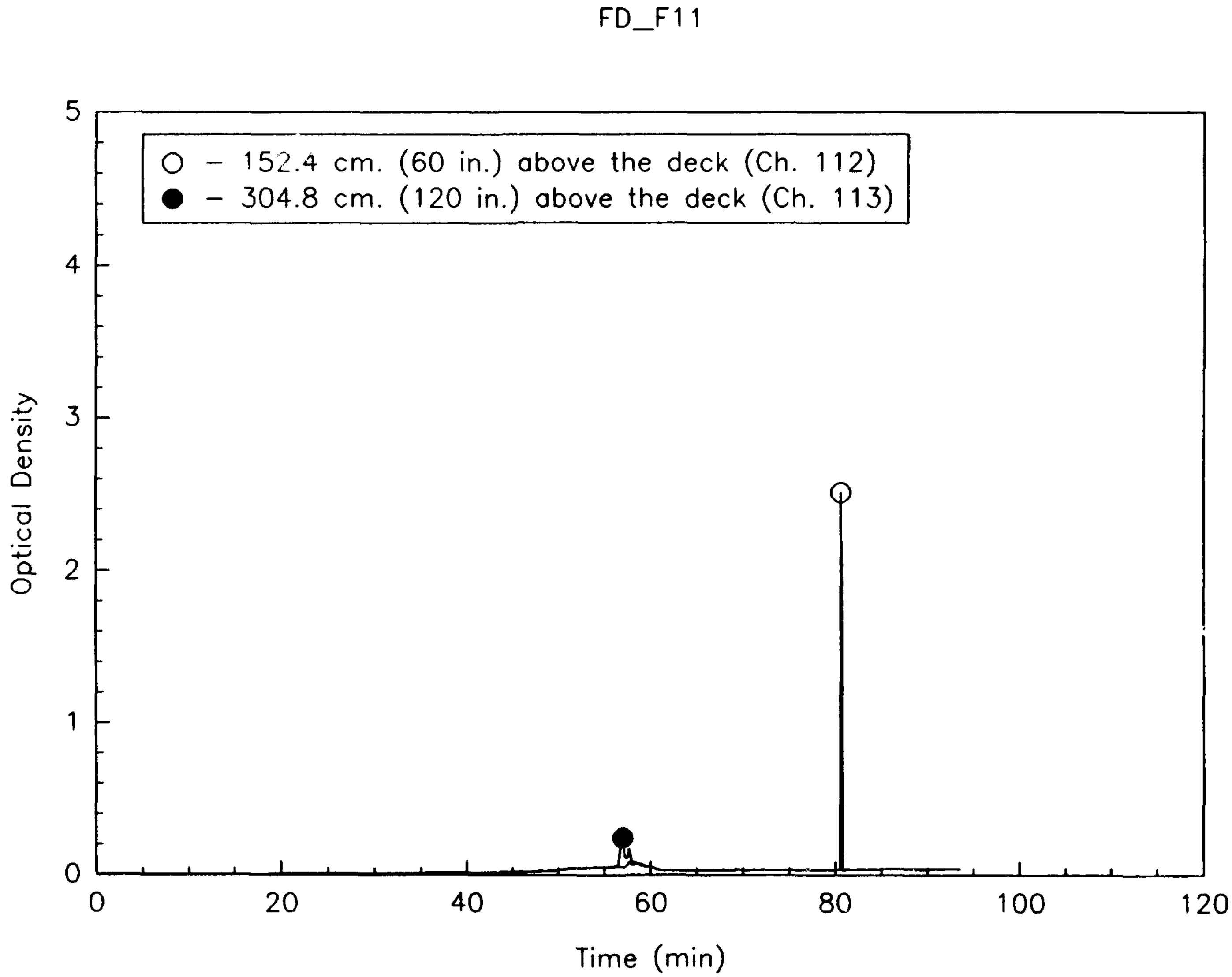

Fig. B133 – Optical density at 2–19–1 starboard passageway

FD_F11

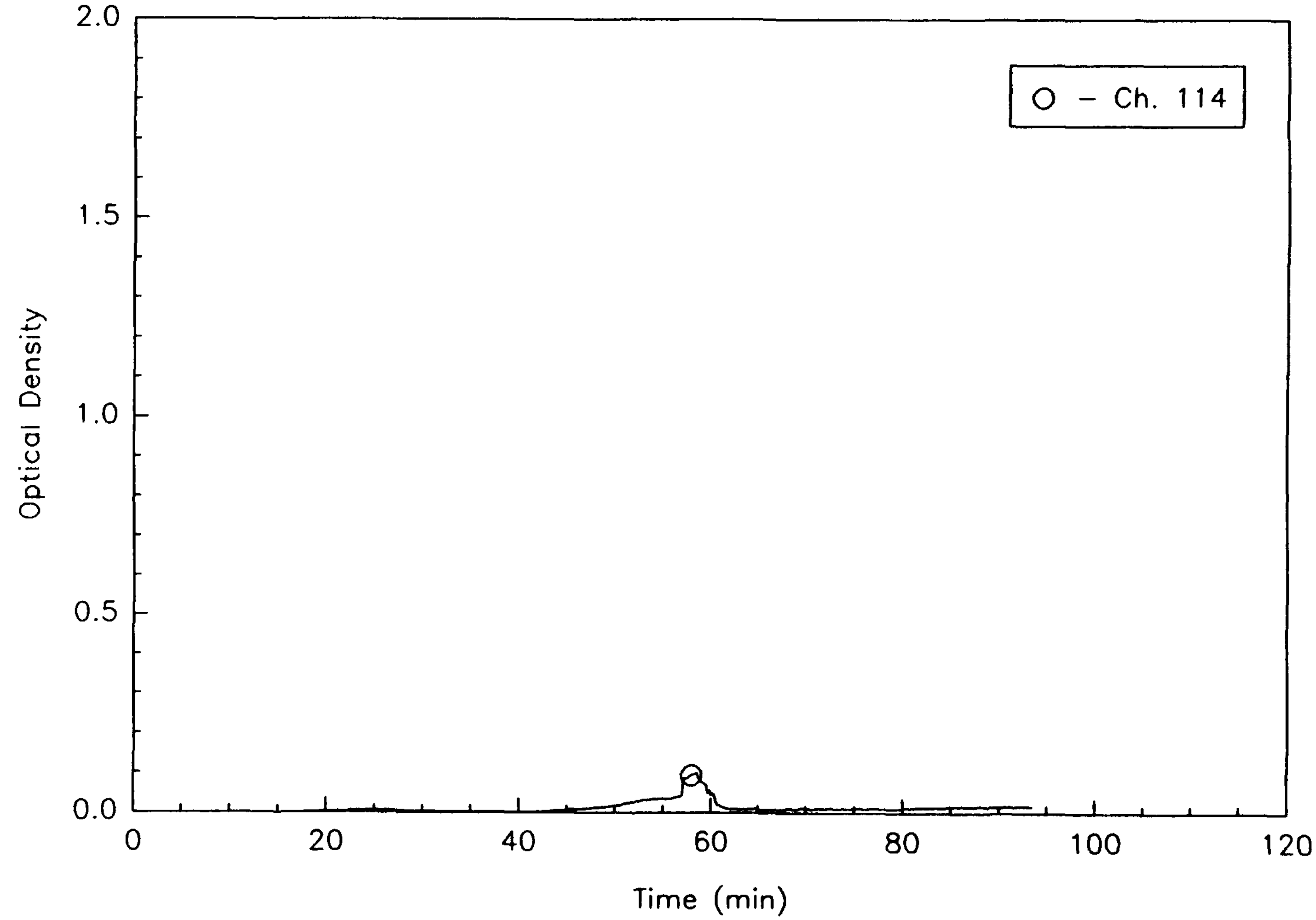

Fig. B134 – Optical density at 2-24-1 in the starboard passageway 152.4 cm. (60 in.) above the deck

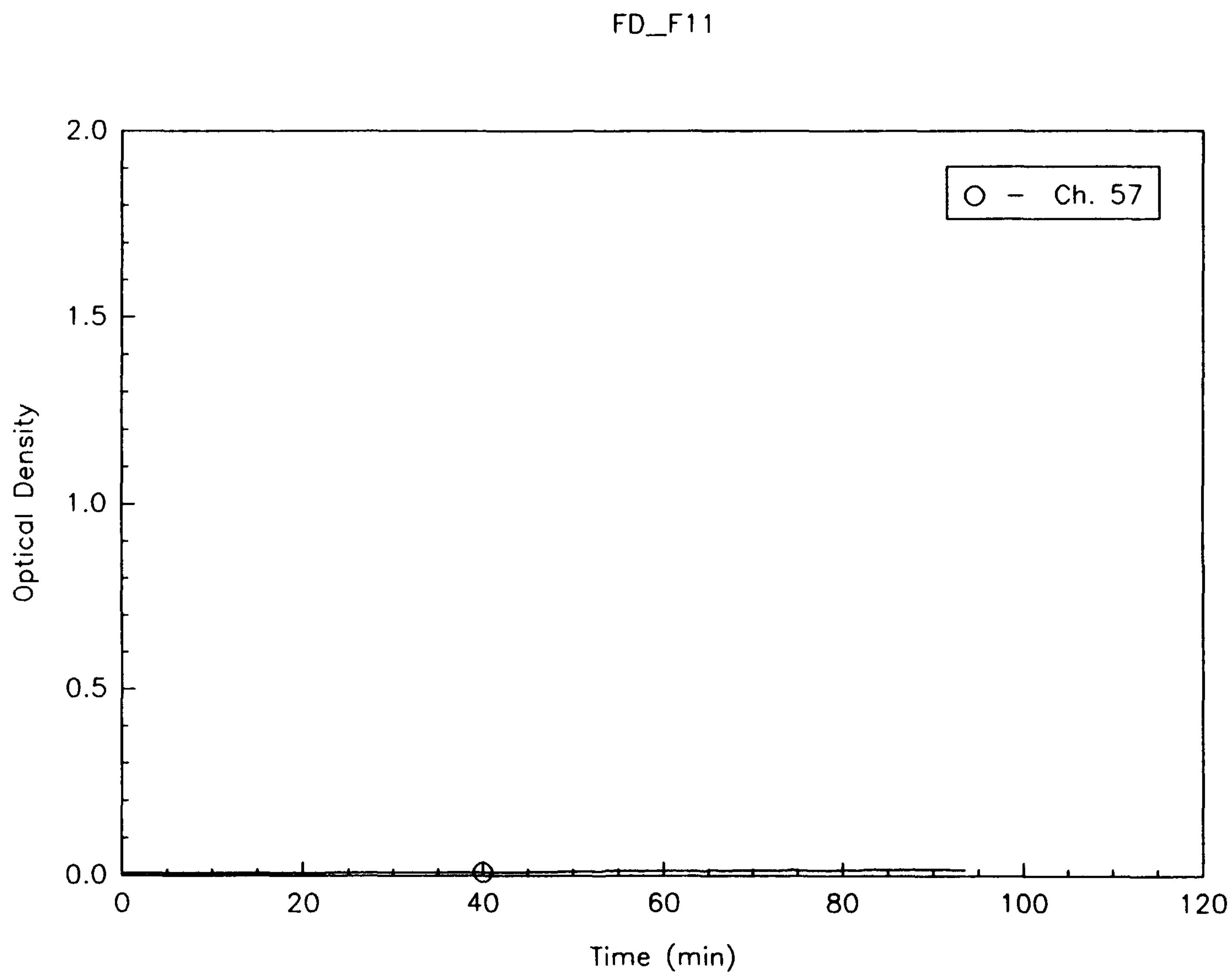

Fig. B135 - Optical density at 2-13-0 athwartship passageway

FD_F11

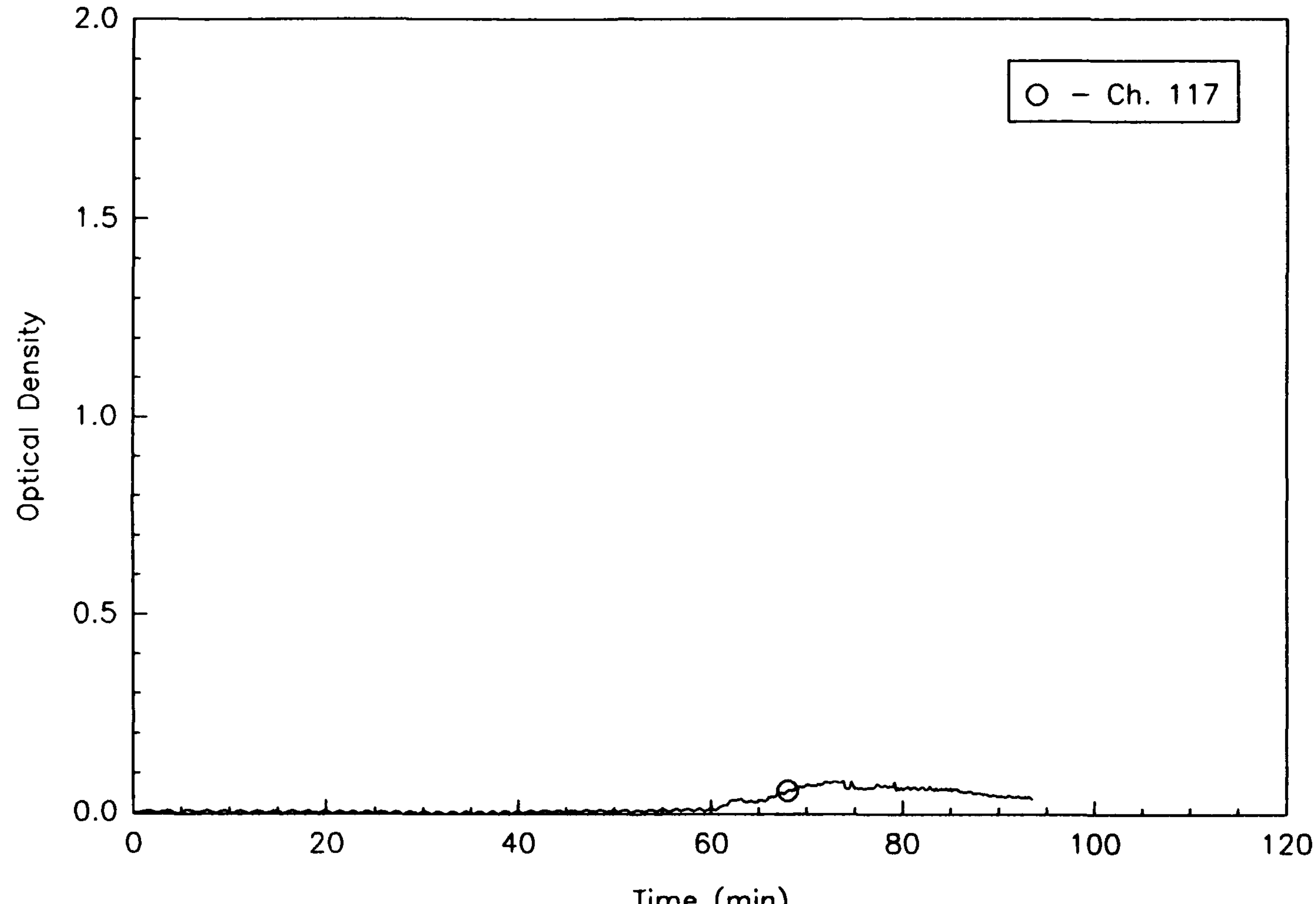

Fig. B136 – Optical density at 1–26–1 in the starboard passageway 152.4 cm. (60 in.) above the deck

FD_F11

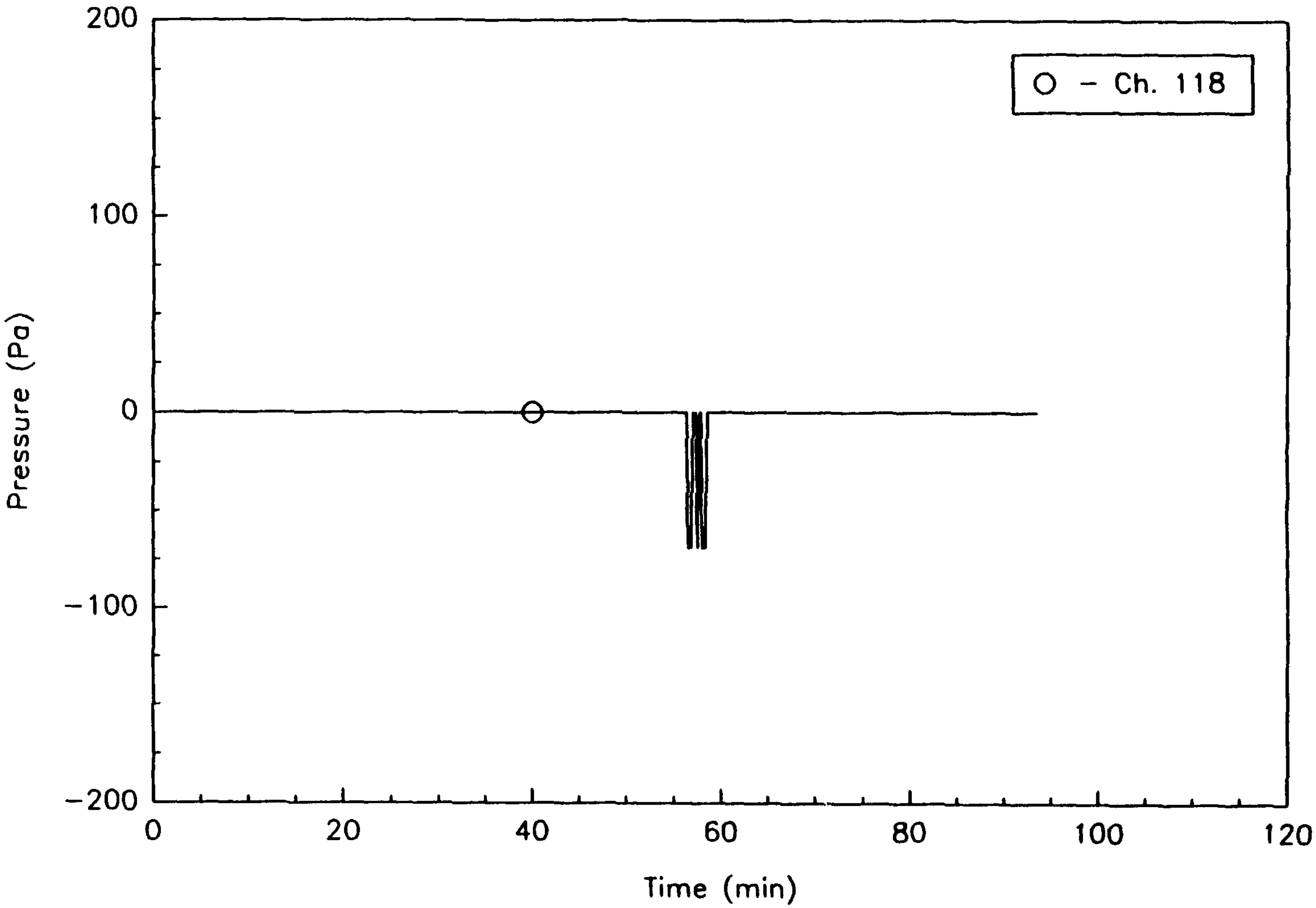

Fig. B137 – Differential pressure at QAWTD 2-15-3

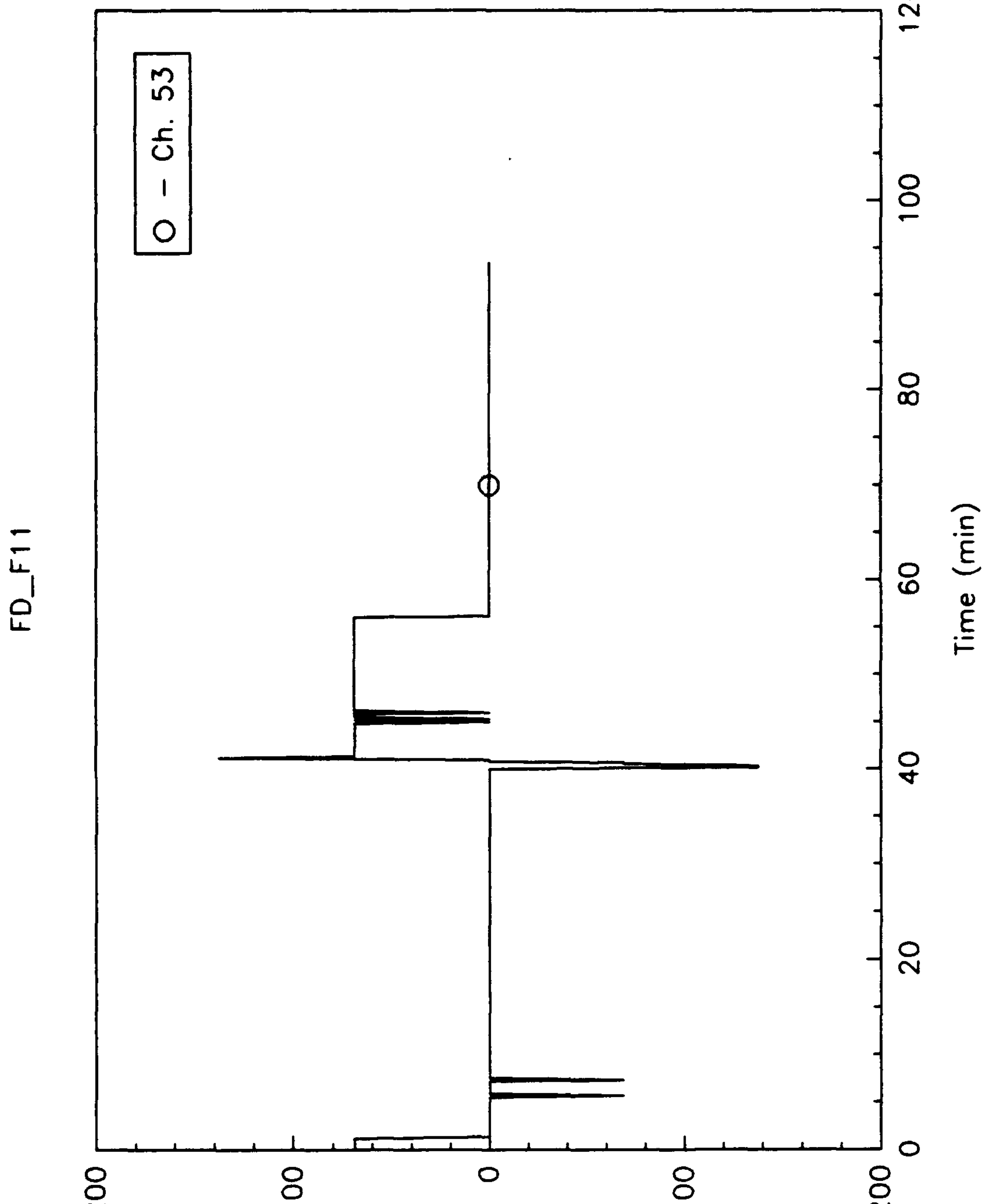

Fig. B138 - Differential pressure at QAWTD 2-17-1

FD_F11

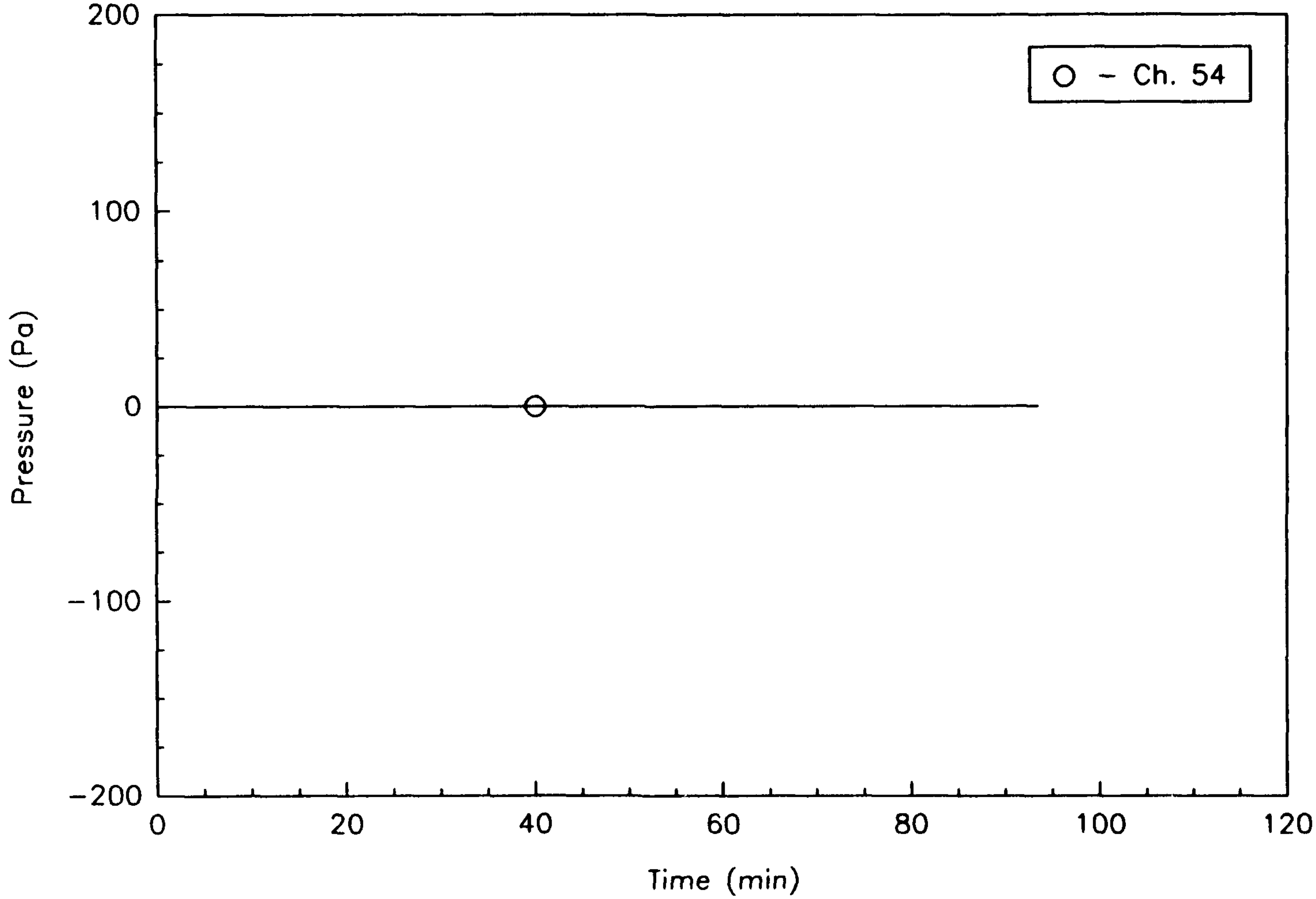

Fig. B139 – Differential pressure at QAWTH 2-20-2

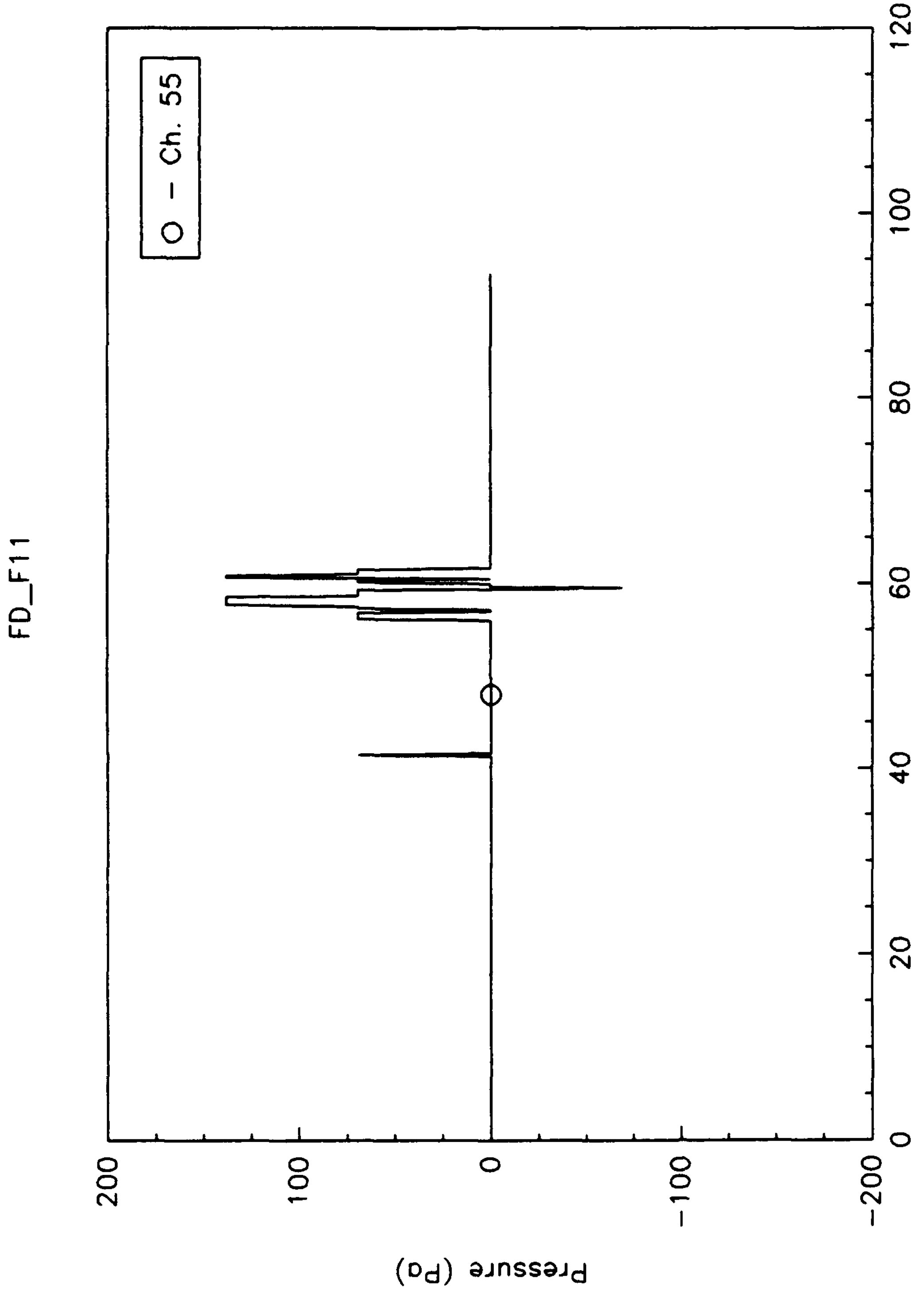

Fig. B140 - Differential pressure at WTS 2-20-1

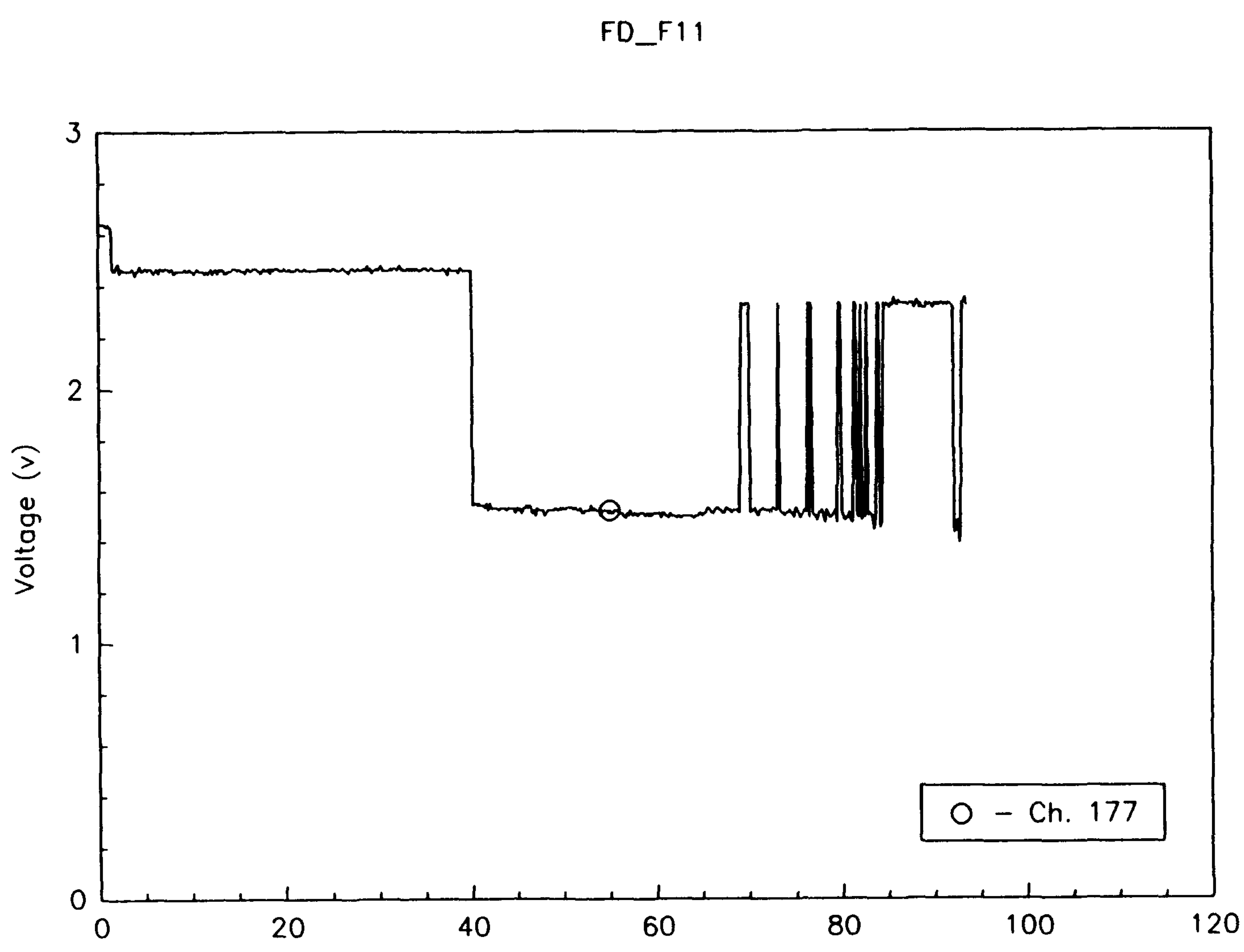

Fig. B141 - Micro switch at QAWTD 3-22-1

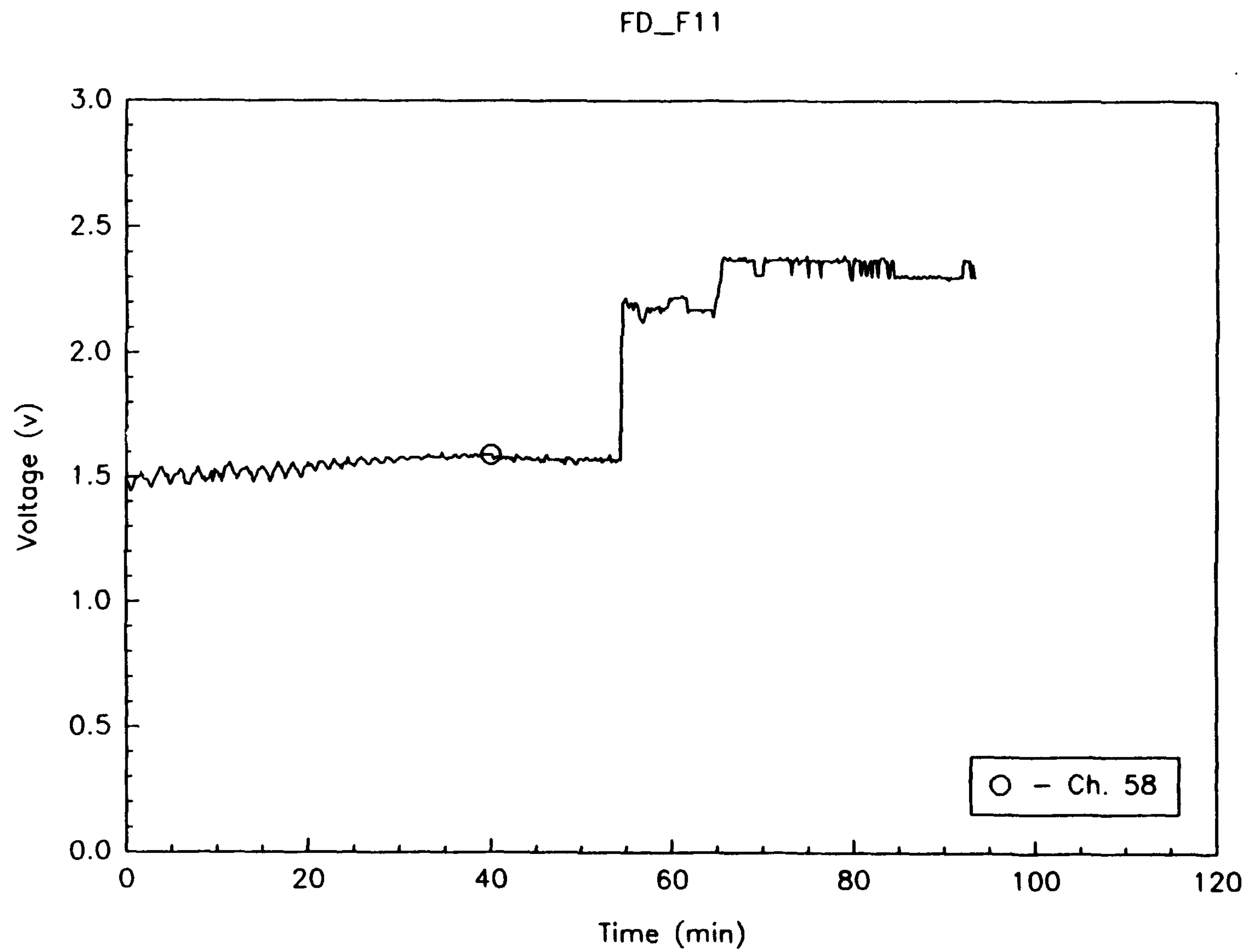

Fig. B142 – Micro switch at QAWTD 2–15–3

FD_F11

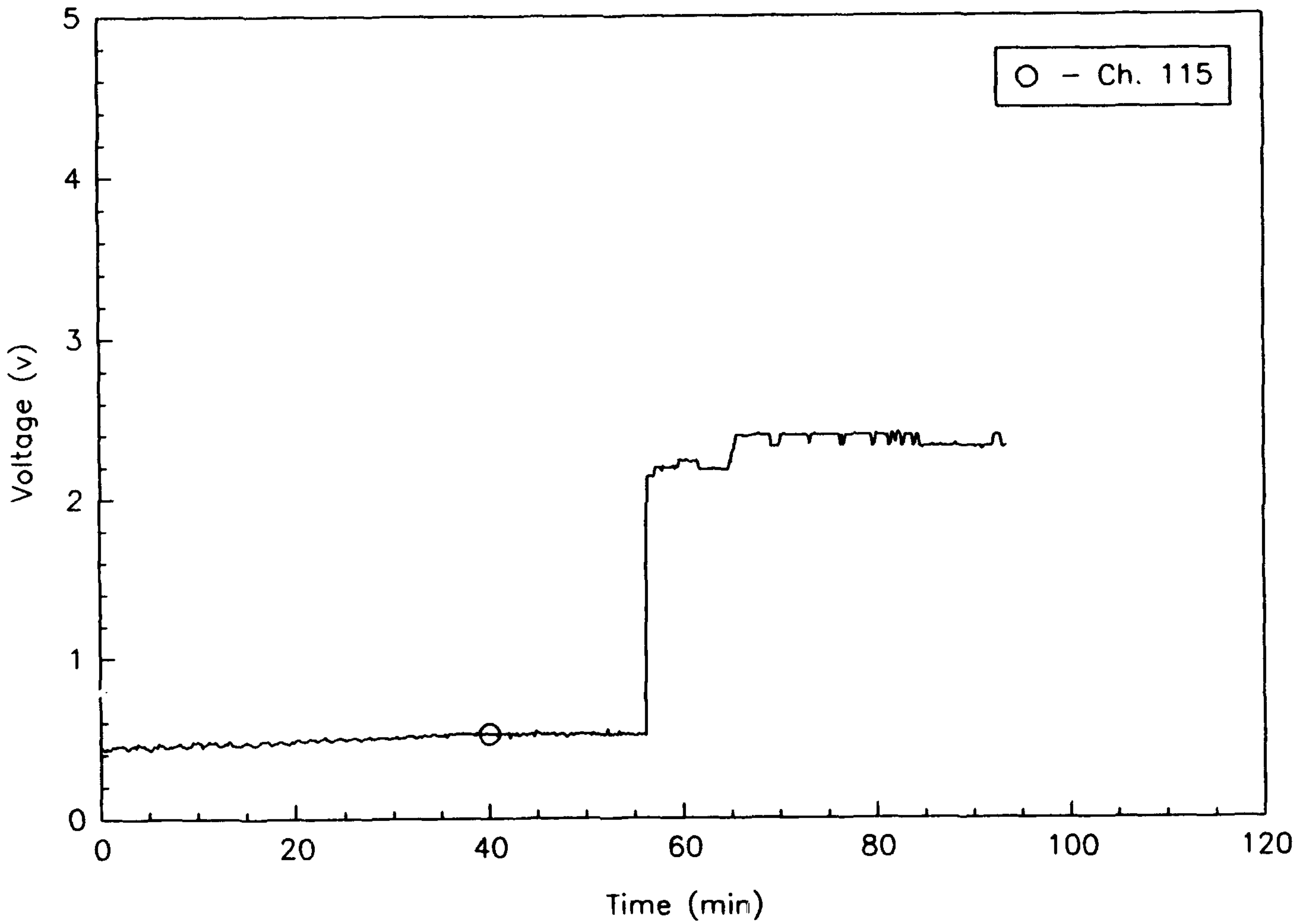

Fig. B143 – Micro switch at QAWTD 2–17–1

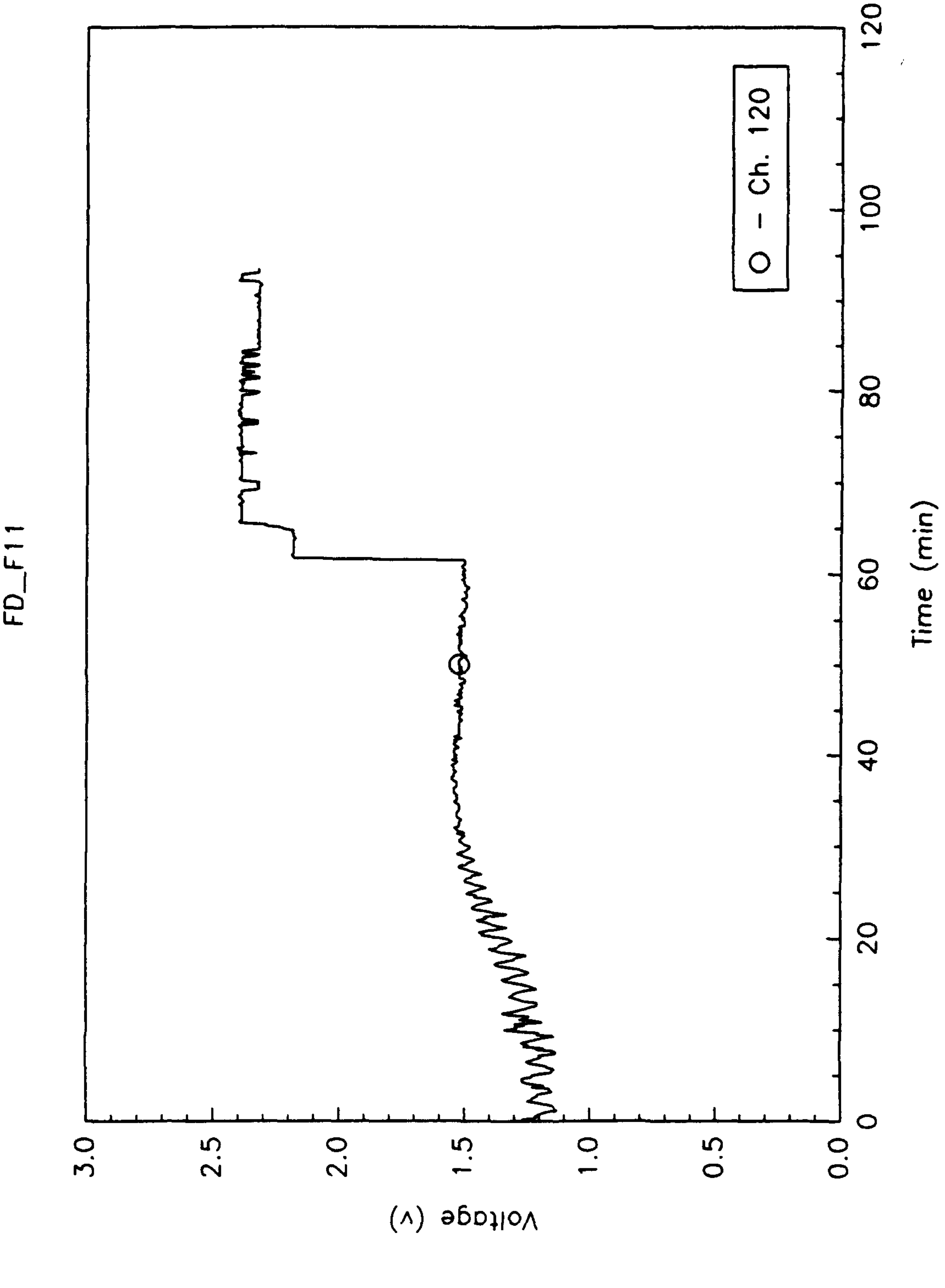

Fig. B144 – Micro switch at WTS 2-21-1

FD_F11

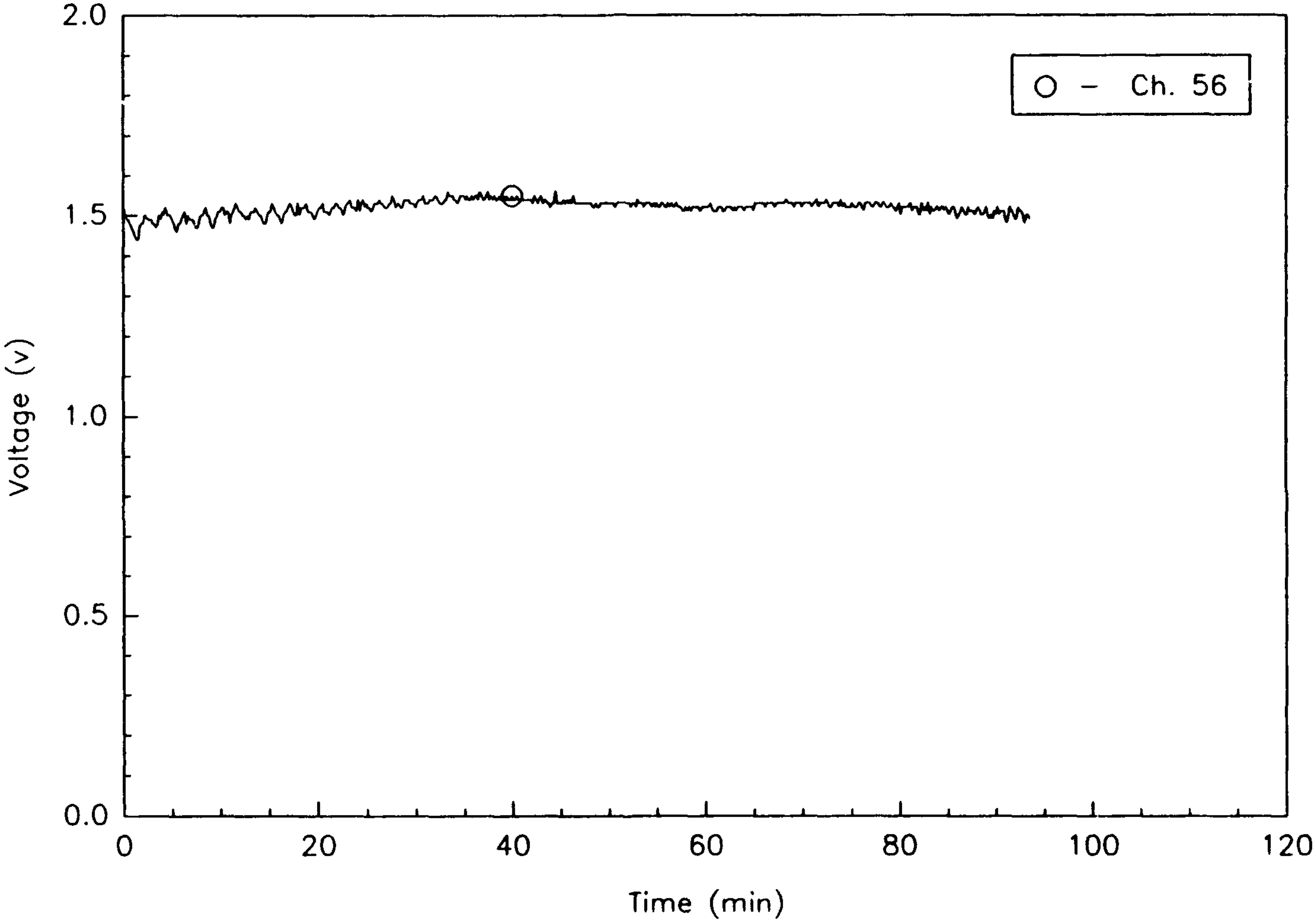

Fig. B145 – Micro switch at QAWTD 2-27-2